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Detection and understanding of water quality events in the drinking water supply network of Barcelona, Spain

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What does the fish know about water where it swims its whole life?

Albert Einstein

La realització d'aquest projecte ha estat possible gràcies a les aportacions de diverses persones. Els meus sincers agraïments a la Mireia Pla, cotutora d'aquest treball, que m'ha guiat i recolzat des de l'inici del projecte, així com també m'ha proporcionat un gran ventall d'eines i metodologies per donar forma i contingut al treball. Voldria donar les gràcies al Xavier Pardo per la seva presència en el meu procés d'aprenentatge a Aigües de Barcelona, tant per discutir gràfics essencials per a la realització del projecte com per donar solidesa a totes les conclusions extretes.

Vull agrair també al Miquel Paraira i al Jordi Raich per la confiança dipositada en aquest projecte i per haver-me ofert l'oportunitat de treballar a Aigües de Barcelona i S::can Iberia. Finalment, voldria agrair a la cotutora del treball, Alícia Maestro, per l'acompanyament i el suport mostrat al llarg del procés.

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SUMMARY

This study is born of the observation of events recorded by a sensor installed in a domestic water network of a building. The aim was to study the consequences of these alterations and find if the water quality inside the buildings differs from the water quality in the city network using different parameters as a threshold of that. Two sensors have been used: one in the pipe inside a building and the other in the general pipe (to control water quality of Poblenou network, in Barcelona city).

The parameters worked are: conductivity, free chlorine, turbidity, temperature, colour, total organic carbon, pressure and flow. With these measurements, different behaviours have been defined according to each parameter and all data that did not follow a trend were classified as events. A total of 20 events were analysed and classified according to whether the alteration was due to an internal incident in the building or an external incident from the city network.

Therefore, alterations in the parameters can be a consequence of an increase of temperature, the number of people using the water at certain time (water demand), the water origin, a change of pressure or flow in the building or an internal dragging in the pipes inside the building.

This study allows to know the alterations that can occur in the quality control parameters inside and outside a building. In this way, it increases the control of the water that reaches the consumers and their quality.

Keywords: domestic network, control parameters, drinking water, quality water, city network, sensors, alterations.

RESUM

Aquest estudi neix de l'observació d'esdeveniments registrats per un sensor a la xarxa interna d'aigua d'un edifici. S'ha volgut estudiar a que són degudes aquestes alteracions i si el comportament de l'aigua a dins dels edificis difereix del comportament de l'aigua a la xarxa de la ciutat. Per aquest motiu, s'han definit uns paràmetres per controlar la qualitat de l'aigua, aquests han estat registrats per un sensor especialitzat en aquest tipus de mesures i se n'han utilitzat dos: un a la canonada de l'interior d'un edifici i l'altre a la canonada d'aigua del carrer (xarxa de la ciutat).

Els paràmetres amb els que s'ha treballat són: conductivitat, clor lliure, terbolesa, temperatura, color, carboni orgànic total, pressió i cabal. Amb les mesures d'aquests, s'han definit diferents comportaments d'acord amb cada paràmetre i totes aquelles dades que no seguien una tendència s'han classificat com a esdeveniments. En total se n'han analitzat 20 i han sigut classificats segons si l'origen de l'alteració era deguda a una incidència interna de l'edifici o a una incidència externa que provenia de la xarxa de la ciutat.

Així doncs, les alteracions dels paràmetres poden ser conseqüència d'un augment de temperatura, de la quantitat de gent que utilitza l'aigua en aquell moment (demanda d'aigua), de l'origen de l'aigua, d'un canvi de pressió en la xarxa interna de l'edifici o d'un arrossegament de partícules a les canonades de l'interior de l'edifici.

Aquest estudi permet tenir coneixença de les alteracions que es poden produir en els paràmetres de qualitat de control a l'interior i exterior d'un edifici i augmentar el control de l'aigua que arriba als consumidors i la seva qualitat.

Paraules clau: xarxa domèstica, paràmetres de control, aigua potable, qualitat de l'aigua, xarxa de la ciutat, sensors, alteracions.

1. INTRODUCTION

Quality control of drinking water is substantially important as it has a human consumption.

The quality of drinking water is regulated in all EU countries by the same community regulations, Directive 98/83/CE. This regulation is based on the recommendations of the World Health Organization (WHO) and is articulated in Spain through Royal Decree 140/2003

The following parameters are used to control the water quality: free chlorine, total organic carbon, conductivity, turbidity, colour, pH, temperature, pressure and flow. To ensure that the water reaching the consumers is in good condition, control sensors that measure these parameters are used. In this study, two sensors record these parameters. One is inside a building and it records the water that flows through the interior pipes of a building, denominate domestic network. The other is on the street and it records the water that flows through the city pipes, denominate city network.

Each parameter shows different behaviour, depending on the time of year and the time of day. The sensors in this work recorded a year of data every two minutes. With this data, behaviours of each parameter have been defined. All data that did not follow established behaviour, was classified as event. Examples of events reported during the study are: very low concentrations of a parameter, point peaks of a parameter, relationships between two parameters or more, etc. What is wanted to investigate is the origin of these disturbances, if it is an internal incident or the cause is found in the city's drinking water network. This will allow an improvement in drinking water control and consequently an improvement human consumption.

This study was born from the observation of events in parameters that record the quality of drinking water. It will identify events that are related to water quality control parameters and identify if there is a direct impact on consumers.

2. OBJECTIVES

The fact of being able to compare the water quality in a building and the city network is interesting because it gives us information about both, domestic and citywide distribution network. This information can be used for future improvements.

The main objective of this project is to find a response to the perturbations that appear in water quality control parameters such as conductivity, pH and chlorine among others in order to improve the quality of drinking water.

Therefore, the study has several secondary objectives as:

- Establish standard patterns of water quality parameters and study their behaviour.
- Identify data that do not follow these patterns as incidences.
- Finding a relationship between incidences in water quality changes in both, domestic and city distribution network, and the changes in quality parameters such as conductivity, pH and chlorine, among others.
- Accrediting online sensors data using regulate laboratory tests in *Aigües de Barcelona* laboratory (accredited by ISO 17025).

3. CONTEXT

3.1 ORIGIN OF WATER SOURCES

In Barcelona, the water reaches the Ter River or the Llobregat River. Depending on the mineral salts and the nutrients contained in the water, it will have a characteristic taste and smell. Due to these differences in the origin, the perception of the water quality is not the same in the citywide.

Every day in Barcelona and its metropolitan area, 680 million litters of drinking water are consumed, equivalent to more than 300 Olympic swimming pools [7]. Aigües de Barcelona responds to these needs providing drinking water from superficial sources (from rivers), underground water resources (aquifers and wells) and, to a lesser extent, desalinated water resources.

***Figure 1**: Map of the province of Catalonia showing the different rivers and deposits future drinking water consumption.*

Figure 1 shows the area occupied by the province of Catalonia. In orange colour the Barcelona area is delimited. Different sources of drinking water supply can be classified as [7]:

- Superficial water resources:

    I. Llobregat River Basin: the surface water captured from this source has a high mineralization and contains organic and inorganic micropollutants. The Drinking water Treatment Plant (DWTP) of Sant Joan Despí and Abrera transform this water into potable water.

    II. Ter River Basin: water from the Ter River is treated at DWTP of Cardedeu. It has a moderate saline concentration and it is rich in calcium, bicarbonates and little organic contamination due to natural self-purification that occurs in reservoirs.

- Underground water resources:

    I. Besòs DWTP: water is collected from a small aquifer belonging of Besòs River. It is drinkable at DWTP of Besòs.

    II. Delta aquifer of Llobregat River: underground water collected from the Llobregat aquifer basin is purified in the DWTP of Sant Joan Despí.

- Desalinated water resources:

    I. Llobregat Desalination Plant (DP): DP provides a good quality of drinking water in high demand episodes. Almost 1% of the water used by Aigües de Barcelona is purified in Llobregat DP. [7]

The waters origin is directly related to its quality.

3.1.1 Ter River

The water from the Ter basin has a moderate saline concentration and it is rich in calcium and bicarbonates, which are more pleasant to taste. Since the Ter River contains a low salt concentration it has a relatively low conductivity. Ter's water has the characteristics showed in Table 1, with which we are worked during this study.

Table 1:*Values from the Ter River collected on April 8 of 2019 at 9:29 am. This is a timely sample; (the parameters do not always have these values).*

Parameter	Units
Residual free chlorine	0.63 mg Cl_2/L
Temperature	27.6 °C
Total Organic Carbon (TOC)	1.2 mg C/L
pH	7.6
Turbidity	0.26 UNF
Conductivity (20°C)	956 µS/cm

3.1.2 Llobregat River

Llobregat River water has a high mineralization, it contains more chlorides and sodium than the Ter River, due to its route through a salt basin. These salts, as a naturals flavour enhancer, highlight the taste of chlorine and a high conductivity (Table 2).

Table 2:*The data collected are from a punctual analysis on August 19 of 2019 at 9:37 am. This is a timely sample; (the parameters do not always have these values).*

Parameter	Units
Residual free chlorine	0.66 mg Cl2/L
Temperature	11.7 °C
Total Organic Carbon (TOC)	2.3 mg C/L
pH	7.9
Turbidity	0.26 UNF
Conductivity (20°C)	44 µS/cm

3.2 DRINKING WATER NETWORK IN THE CITY OF BARCELONA

Aigües de Barcelona, legally called Societat General d'Aigües de Barcelona, is the company responsible for managing the services related to the integral citywide water cycle, such as the supply of drinking water and sewerage, also in the 36 municipalities of Barcelona metropolitan area, serving almost three million inhabitants.

Aigües de Barcelona network is mainly supplied with water of Llobregat River in the southern sector of the city, and Ter River in the north. At the northern sector, Ter's water is treated at Cardedeu DWTP and this contribution is reinforced by Besòs DWTP.

At the southern sector Llobregat River reaches the DWTP of Sant Joan Despí and Abrera (it has less capacity). To increase the demand, water is also taken from aquifers and DP of Llobregat. Figure 2 shows the location of the aforementioned facilities.

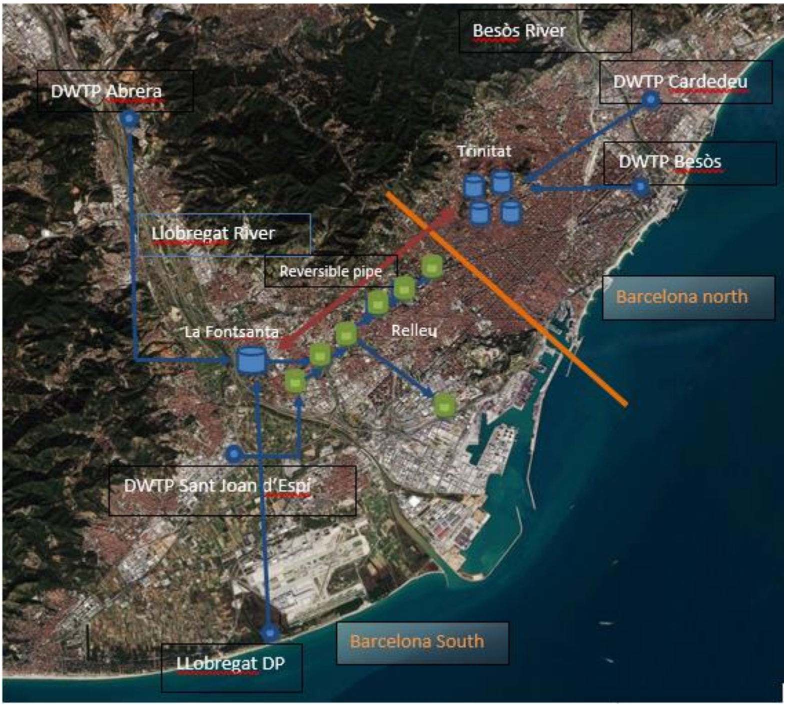


Figure 2: *Map of Barcelona city showing the sources of supply, main pipelines and reservoirs.*

In order to distribute the water, the city is divided according to the height of the area, using the force of gravity. Therefore, different pressure floors are defined, and the water is distributed under a certain pressure according to the height at which it is located

As it says in [1]: The treated water at the DWTP of Cardedeu is sent to the Trinitat deposits. From these deposits, the water is distributed through different pressure floors and it is supplied to the northern part of Barcelona.

The water treated at the Abrera DWTP is sent to La Fontsanta deposit. This deposit also receives treated water from the Llobregat DP. This tank is connected to Relleu (green deposits in Figure 2) deposit which distributes water according to pressure floors to supply water to the southern sector of Barcelona.

Depending on the needs, water can be sent from Trinitat to La Fontsanta or vice versa through a reversible pipe. (Appears in red in Figure 2).

3.3 NETWORK DISTRIBUTION

As defined in [2] The supply distribution network is defined as:

“The set of pipes and all its elements of manoeuvre and control, which is installed within the territorial scope of the supplying entity and on public or private land, prior constitution of the appropriate easement, conduct potable water under pressure, and which kites are derive for subscribers.”

To facilitate the water distribution, the network is organized with pressure floors to supply water by gravity. Therefore, different deposits provide water throughout the city. The water distribution is divided into different sectors. In Figure 3 there are 139 sectors of Barcelona, each one provided with a specific deposit.

Sectorization is the hydraulic delimitation of drinking water distribution networks. The sectorization defines the form and inputs that the consumer sector will have, so that these are controllable and can managed actively and independently.[3]

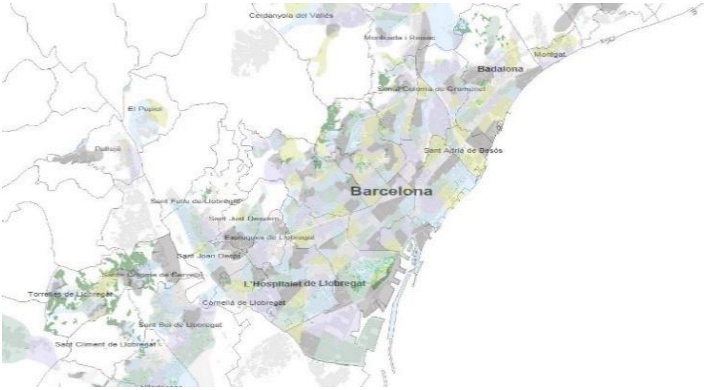


Figure 3*: Map of Barcelona where the different sectors appear.*

3.3.1 Pipes

The distribution network has a series of pipes that can be classified into:

- Main or artery: it transports water from the intake points (deposits, etc.) to the secondary pipes. The advantage of a large artery is that it distributes, and, in turn, it minimizes load losses. Furthermore, it allows a control of the water that circulates through the artery. This artery controls all the water that is distributed in each sector.

A drawback of this pipe is the control of residence time. Water cannot circulate for a longer residence time since it causes an increase of trihalomethanes or bacteria.

- Secondary pipes: they are radial pipes that are in connection with distribution pipes. They make a connection between the main artery and the distribution pipe.

- Distribution pipes: They are responsible to transport water to the connection points.

- Connection point: final pipes that connect the distribution pipes to the final consumer. These are the final point of the network distribution system. [3]

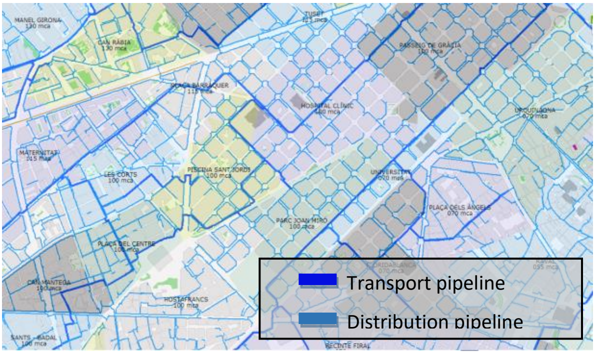


Figure 4: *Part of the map of Barcelona. Different pipes are drawn transport and distribution.*

In Figure 4, it can be observed the main pipes and the distribution pipes. Main pipes are dark blue and the distribution pipes are light blue. As it can be seen, the diameter of the transport pipe is larger as they carry more water.

3.3.2 Drinking water network distribution of Poblenou

Llacuna is the sector where this study was made. It is located in the northern part of the city and has an area of 65ha approximately. Figure 5 shows Llacuna sector. This one is delimited by other sectors as Vila Olímpica, Glòries and Poblenou – Mar Vella.

Figure 5: *Part of the map of Barcelona. There are differentiated sectors of the city. Each of them painted in a different color.*

The sector where all the sensors are located is called Llacuna 055 and is shown in purple in the Figure 5.

3.3.3 Location of sensors

This study was executed using two sensors located in two different places in the drinking water distribution network. The technical specification of these two sensors appear in the section 4.3

Pipe::scan was installed in an office located in Ciutat de Granada Street. The aim of this installation is to control the water quality in domestic distribution network.

Nano::station is a sensor with the same objective of water quality control. The difference is that it controls the water quality in the distribution pipeline network. It was installed in Dr. Trueta Street. In Figure 6 it can be seen pipe::scan location (pink point) and Nano::station location, (yellow point).

The water in Llacuna sector arrives through a reversible transport pipeline. This pipe is connected to the distribution pipes, which make the water reach the connection point. This pipe is indicated with a dark blue area in Figure 6.

The reversible pipe can bring water from Llobregat's River or from Ter's River. This means that in this sector we can find water from the Llobregat and water from the Ter. There are two checkpoints, depending on the water demand. Only one checkpoint is open (Àlaba). Nevertheless, if it is necessary, both checkpoints (Àlaba and Llull) can be opened. Figure 6 shows the different location of the materials that have been used to perform the study.

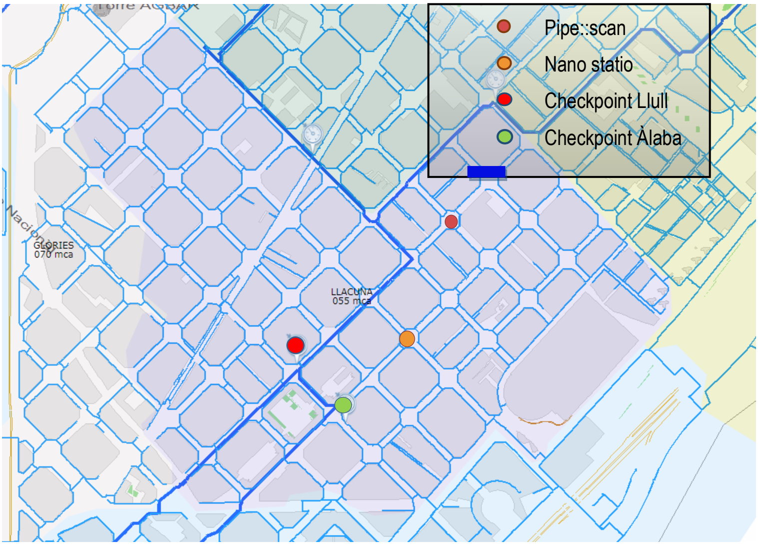


Figure 6*: Different locations of the sensors and control points in the Llacuna sector. The distribution and transport pipe also appear.*

4. MATERIALS AND METHODS

4.1 SENSORIZATION OF THE DISTRIBUTION NETWORK OF POBLENOU

Aigües de Barcelona Company has a network of hundreds of sensors in order to have a data record and a good drinking water circulating through the network.

Sensors are devices that can transform physical or chemical quantities, called instrumentation variables, into electrical quantities.[4]

The probe collects the information and transducer transforms it into a measurable form of energy. This device is capable of transform the energy that carries the information of the sample in an analytical usable signal.[4]

Figure 7 shows the basic sensor structure operation:[5]

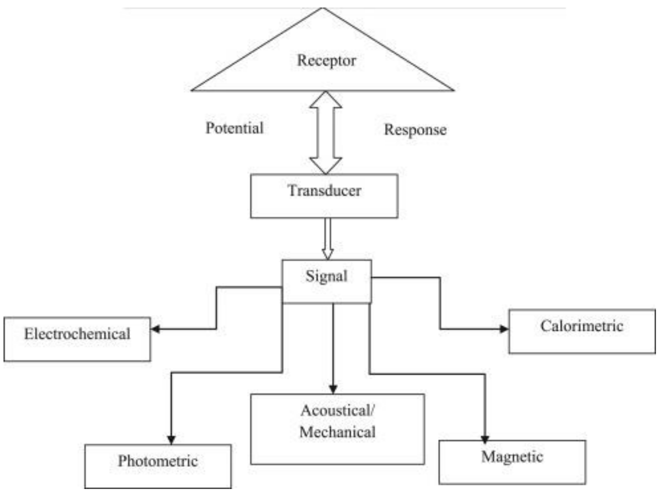


Figure 7: *Principle of chemical sensor-based mechanism. [5].*

4.2 PARAMETERS

To be able to control the water quality, it is necessary to define parameters:

- Free Chlorine: Chlorination is a procedure to disinfect the water and maintain it in a good healthy level. Free Chlorine is a parameter to control the level of Chlorine in optimum conditions. The units of free chlorine are [mg/L]. The probe that measures this parameter is called chlori::lyser and measures the concentration of free chlorine [mg/L] due to its principle of amperometric measurement.

- TOC: It is the amount of carbon found in an organic compound. It is used as a parameter for water quality control as it provides information on the amount of organic matter found. The sensor that analyses TOC concentration [mg/L] is called i::scan and it is a multiparametric probe.

- Turbidity: It is understood as the degree of transparency lost by water due to the presence of suspended particles. The greater the number of solids suspended in the liquid, the greater the degree of turbidity. The units of turbidity concentration are Formazin Turbidity Unit [FTU]. The sensor that analyses concentration turbidity [FTU] is called i::scan.

- pH: pH indicates the concentration of hydrogen ions presents in certain solution. In the production of drinking water, the pH::lyser probe is used to control chemical and physical treatments that are characteristic of changes in pH, such as neutralization, flocculation o mixing of water from different sources.

- Colour: it is the ability to absorb certain radiation from the visible spectrum (380 to 750nm). The colour, by itself, does not disqualify water as potable but can make it reject by aesthetics. The sensor that analyses the colour concentration [Hazen] is called i::scan.

- Conductivity: electrical drinking water conductivity is an essential indicator of dissolved salts amount and, therefore, the purity of the water. In addition, it also provides us information about water's origin. The condu::lyser is a multiparametric probe that determines on-line the concentration of dissolved salts [µS/cm].

- Temperature: it is a control variable that changes according seasonality, day-night changes or different water sources [ºC]. This parameter is measured by i::scan

- Pressure: it measures how much force [N] per unit of surface [m^2] circulates through the pipe. Units of pressure are Bar. It is a control parameter because, if there are physical alterations to the pipes, the pressure detects it. [9]

- Flow: it is the quantity of water passing a given point in a pipe during a given period. It measures the volume of fluid, in this case water, which passes per unit time, usually measured in [L/h]. [9]

4.3 SENSORS

This study was perform using two measuring equipment.

4.3.1 Pipe::scan

The Pipe::scan has several water quality control probes. It is a sensor system to monitor the drinking water quality in pipes under pressure.

Water quality data are sent to the PLC (Power Line Communication) computer called con::cube. From there, they can be extracted for further analysis.

Figure 8 shows the sensors that are located in Ciutat de Granada Street at s::can's office. They were installed a year before the kick-off project. There was a year of data recorded with their respective events. Data are recorded every two minutes without stops. To extract the data from the sensor, a pen drive is used to transfer the information to a computer for a future data processing. This sensor can be installed in a pipe. In this case, it is connected in by-pass simulating a pipe.

Figure 8 shows how the water enters through a pipe inside the sensor, the control quality analyses are executed. Each sensor controls the corresponding parameter. When the analysis is finished, the water goes out through another pipe.

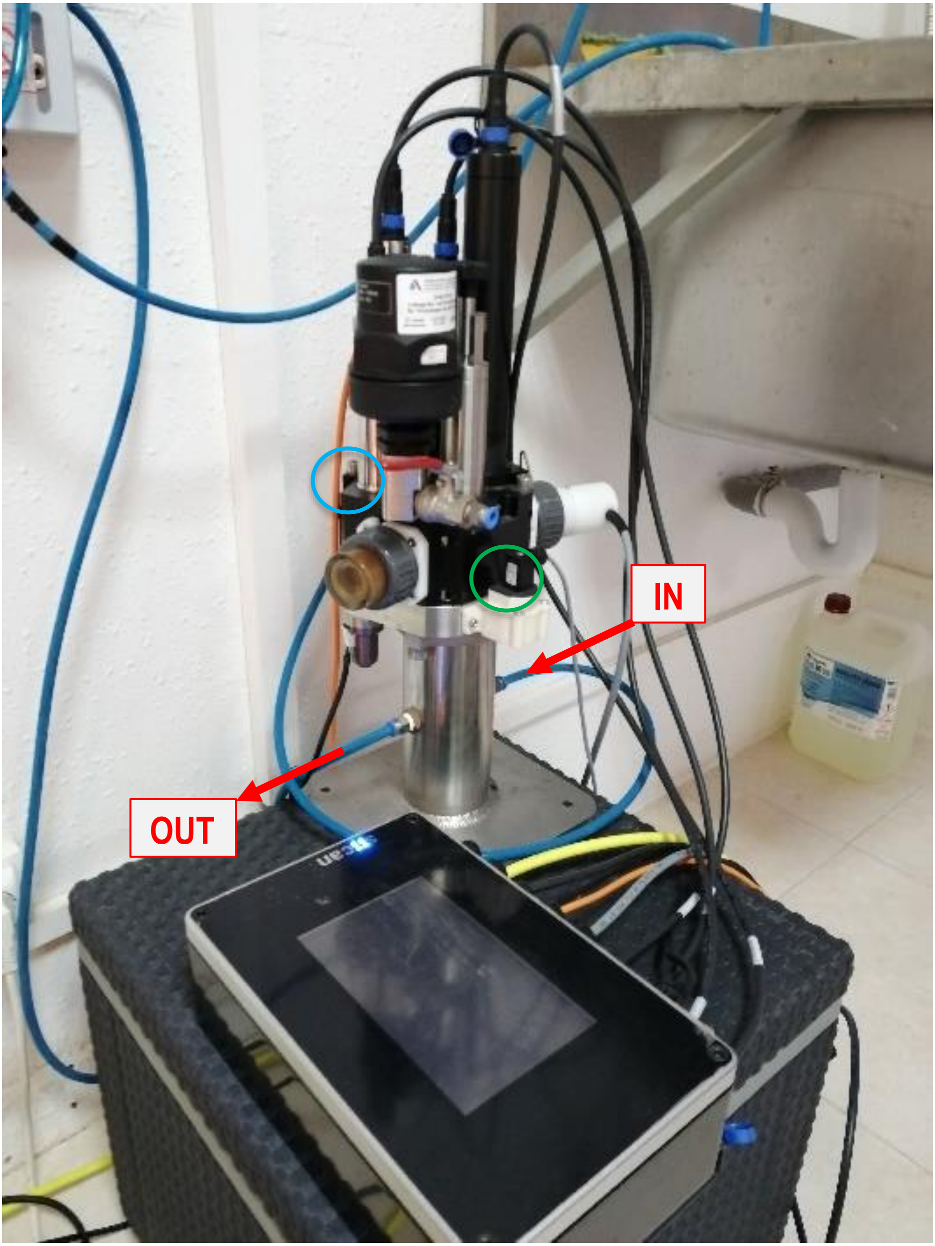


***Figure 8**: Installation of the pipe::scan located in the office of s::can in the street Ciutat de Granada*

The pipe::scan consist of different sensors. Table 3 shows each sensor and the parameters that they measure:

Table 3: *Sensors that device the pipe::scan and what parameter they measure. The units of measure of each parameter appear.*

	Chlori::lyser 	I::scan 	pH::lyser 	Condu::lyser 
Free Chlorine [mg/L]	x			
TOC [mg/L]		x		
Turbidity [FTU]		x		
pH			x	
Colour [Hazen]		x		
Conductivity [µs/cm^3]				x
Temperature [ºC]		x		x

Pressure and flow are not measured by sensors. The pressure is measured with a pressure regulator and flow with a flowmeter, highlighted in green and blue circles on the Figure 8, respectively.

Depending on the parameter they measure, the sensors can be classified into different types. Table 4 shows the corresponding measurement technique of each sensor.

Table 4: *Operation characteristics of the pipe::scan sensors.*

	Amperometric	Spectrophotometric	physical
Chlori::lyser	x		
I::scan		x	
pH::lyser			x
Condu::lyser			x

All physical probes are based on the *plug and measure* principle work with a simple plug-in connection where the power supply and communication of the s::can control units is made.

4.3.2 Nano Station

The Nano station is the sensor that is located in Dr. Trueta. This sensor has been specially installed to do this study, since it measures the water of a transport pipe. It is installed in a sample closet (Figure 9).

What it does is to deflect through the by-pass the water that circulates through the pipe and analyses it. Then the water is sent again to the pipe.

As it can be seen in Figure 9 this device works with electricity, in this case, the station has connected to a battery.

The water is analysed via by-pass that is made in the distribution pipe of Street Dr. Trueta. The water enters through a pipe, the corresponding control quality analyses are done, and it is returned. To grab the data, a pen drive is attached to the con::cube (the screen) and the information is removed.

Figure 9: *Installation of Nano station on Dr. Trueta. This facility is inside a sampling cabinet owned by Aigües de Barcelona*

This sensor measures data every five minutes. As a result, it consumes a lot of battery. This fact caused some disadvantages when conducting the study since the Nano station has been left without a battery and therefore there are data intervals that are not registered.

The specifications table is the same as Pipe::scan (Table 3) since it measures the same variables. The only difference that presents is that the Nano Station does not have a pressure gauge and therefore we do not have pressure data. The flow variable only indicates if there is fluid circulating (1) or not (0).

4.4 WORK PLAN METHODOLOGY

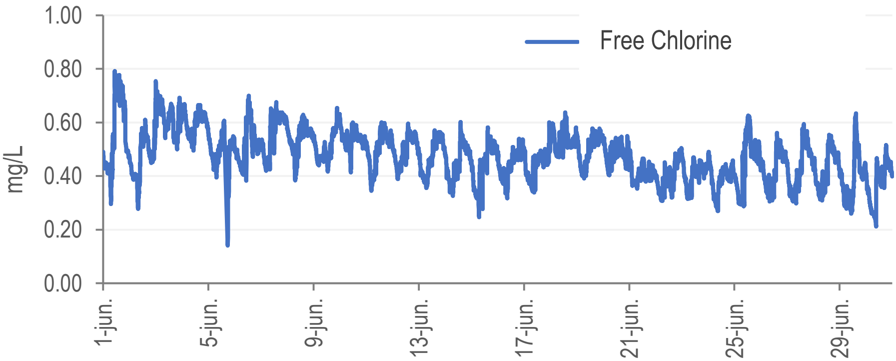
The study began with a year of data recorded by the sensor pipe::scan. These data were classified monthly and were recorded in order to observe the behaviour of the different parameters according to the month.

Microsoft Office 365 ProPlus Excel Version 1911 is the program where all the data are treated.

Table 5 is a fragment of the document where all the data are stored. As you can see, all the aforementioned parameters appear. Based on these data, each variable was recorded according to the month.

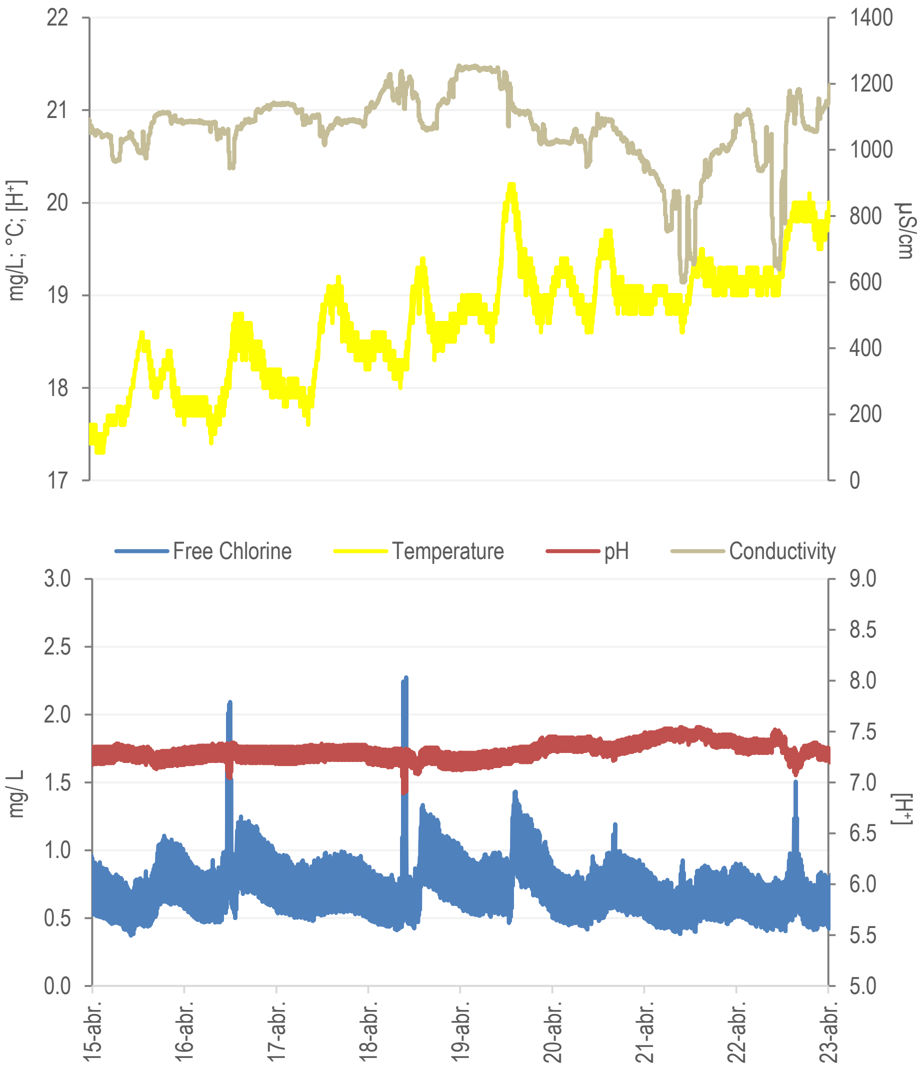
Table 5: *Fragment of data extracted from the pipe::scan log. Data recorded every two minutes in the water that circulates in the office of s::can at Street Ciutat de Granada*

Date/Hour		Free Cl_2	Flow	P	pH	Cond	Turb	TOC	Colour	T
01 – 06 – 2019	0:00	0.381	14.4	3.45	7.52	893	0.211	0.6	4.3	21.7
	0:02	0.377	14.3	3.48	7.52	893	0.214	0.6	4.3	21.7
	0:04	0.376	14.4	3.40	7.52	893	0.209	0.6	4.3	21.7
	0:06	0.376	14.4	3.55	7.52	893	0.236	0.6	4.3	21.7
	0:10	0.372	14.3	3.31	7.52	894	0.261	0.6	4.3	21.7



Graph 1: *Analysis of the chlorine concentrations recorded by the pipe::scan from June 1, 2018 to June 30, 2018.*

All parameters recorded by the pipe::scan are plotted monthly to analyse which patterns are being followed. Graph 1 shows the monthly behaviour of free chlorine during June 2018. This comparison has been done with all the parameters and it can be seen in Annex 1.

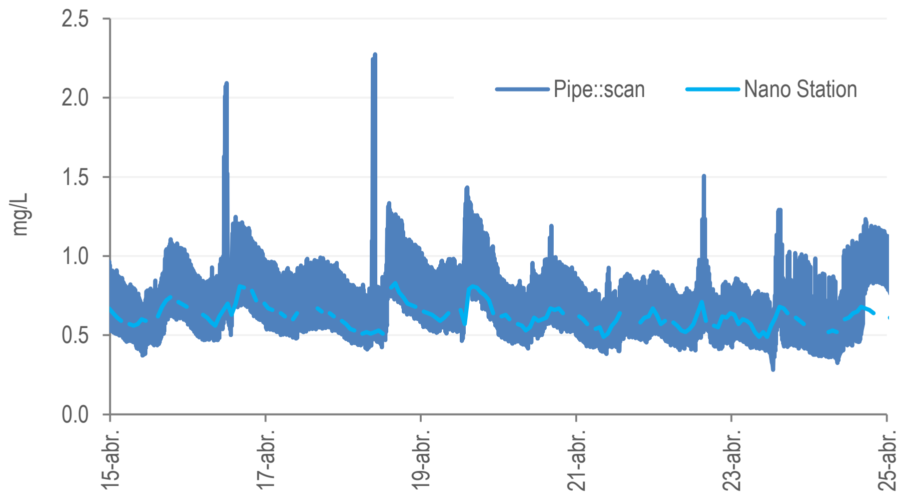


***Graph 2:** Comparison between the parameters of chlorine, conductivity and temperature from April 15, 2018 to April 25, 2018. Parameters measures with the pipe::scan.*

From the monthly analysis, behaviours of each parameter have been defined. All those data that did not follow the established pattern, have been classified as punctual events. All these occasional events have been compared with other parameters registered with the same sensor. (Graph 2).

In addition, the same parameter registered for two different sensors has also been compared. This comparison has not always been possible since the external sensor has not always had data.

Graph 3 shows the chlorine parameter registered by pipe::scan and free chlorine parameter registered by nano::station.



Graph 3: *Free chlorine trend from May 25, 2018 to May 28, 2018. Parameters measured by the pipe::scan and the nano::station.*

Based on these comparisons, all the occasional events have been classified.

In order to guarantee the quality of this study, a series of test have been executed. Water samples from s::can's office (where there is the pipe::scan) and the sampling cabinet (where there is the nano::station) were taken in order to analyse in Aigües de Barcelona's Laboratory.

Table 6 shows the data measured by the pipe::scan and the data analysed in the laboratory. This same test was also carried out with the Nano station.

Table 6: *This table shows the comparison between the parameters measured by the pipe::scan and the parameters analysed in the Aigües de Barcelona laboratory. Yu can see a more accurate explanation in Results and Discussion section.*

	Pipe::scan	Laboratory	Pipe::scan	Laboratory	Pipe::scan	Laboratory
Data	14/5/19	14/5/19	31/05/19	31/05/19	14/6/19	14/6/19
Conductivity	808	744	696	668	926	855
pH	7.53	7.6	7.58	7.73	7.5	7.74
TOC	0.7	1.1	0.7	1.6	0.8	1.6
Free Cl_2	0.47	0.43	0.391	0.51	0.585	0.57
Turbidity	0.252	0.300	0.315	0.310	0.363	0.387

As it can be seen, the parameters measured by the pipe::scan do not show much difference with the parameters analysed in the laboratory. Therefore, the analysed data will be correct.

5. RESULTS AND DISCUSSION

This study classified events according to whether the cause was on the domestic network or the city network. A total of twenty events have been analysed but only the most significant will be presented (Annex 2).

All the data analysed are from the pipe::scan located inside the building, that is, domestic network. Some events happen only inside the building and others happen in the city network. That is why two groups have been made:

- Network events: events that have been detected both in the domestic network and the city network and whose origin is outside the building.

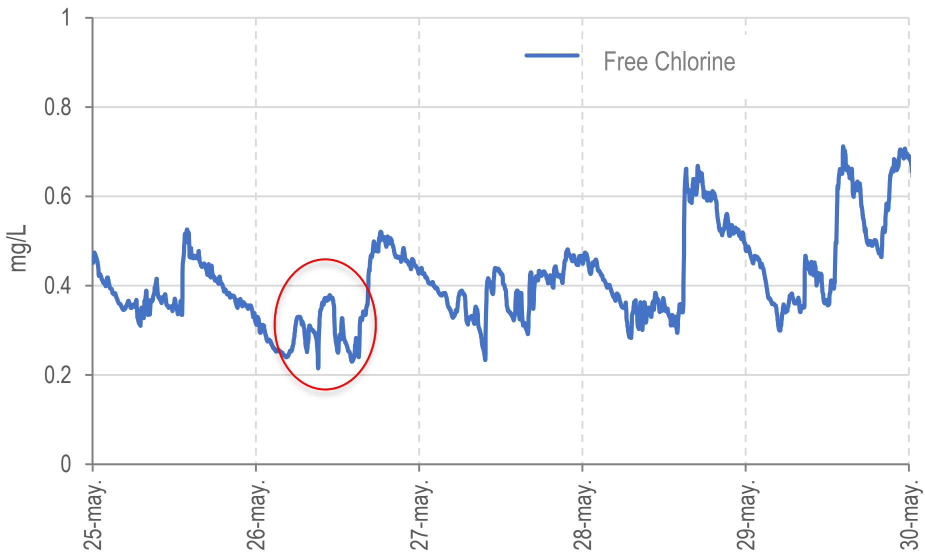
- Domestic events: events that have only been detected in the domestic network and have no relation to the city network.

In order to make the classification more understandable, the graph that shows the values that do not follow the established patterns is first presented. Then, there are comparative graphs between parameters and finally the origin of the incident is explained.

5.1 NETWORK EVENTS

5.1.1 Decreased chlorine due to a change in temperature

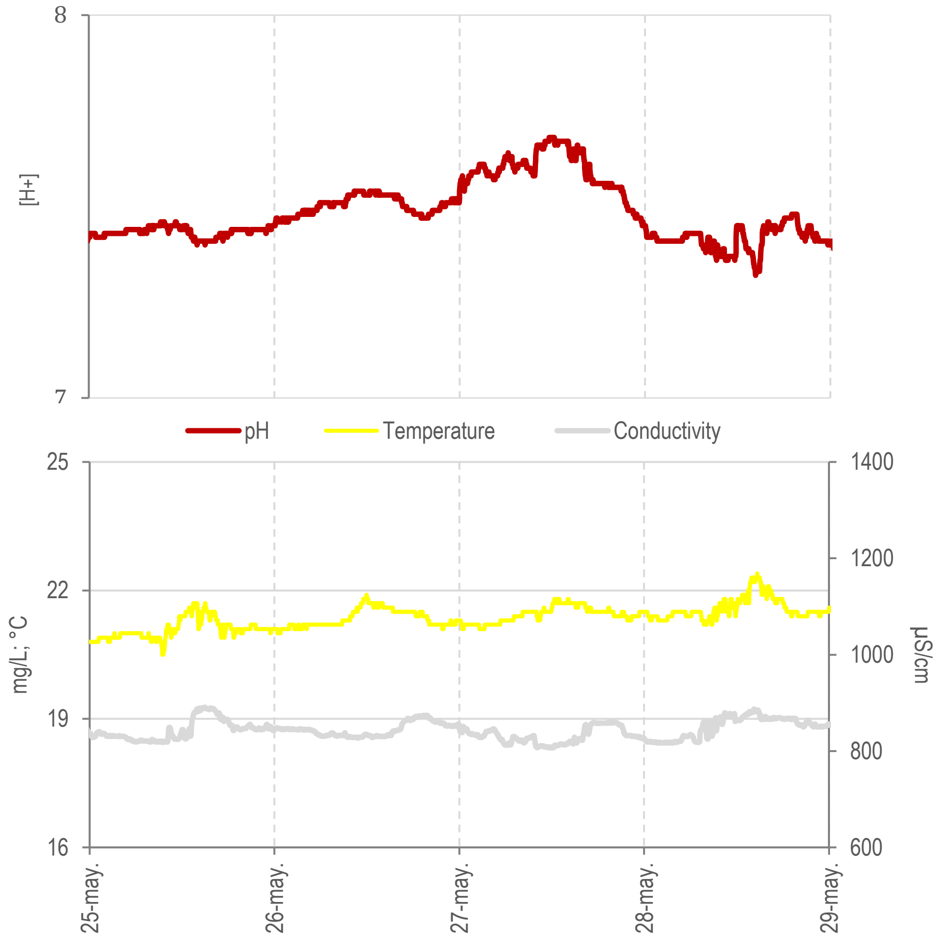
It has been observed that temperature changes have implications for water quality control parameters. The next event (Graph 4) has been analysed because of a very low chlorine concentrations was detected by pipe::scan on domestic network. In the analysis of the monthly behaviour of free chlorine, chlorine concentrations move from 0.4 to 0.6 mg/L. In this case, the concentration of free chlorine reaches 0.2 mg/L. A very low value.



Graph 4: *This diagram is explaining the behaviour of free chlorine from May 25 to May 28. The data are recorded by the pipe::scan.*

Graph 5 shows the behaviour of free chlorine from May 25 to May 30. This parameter shows oscillations ranging from minimum values of 0.2 mg/l to maximum values of 0.7 mg/l. The lowest concentration of free chlorine is on May 26 at 9:36 a.m. and have a value pf 0.21 mg/l Appears on the graph circled in red.

Chlorine behaviour analysed in Graph is compared with conductivity, temperature and pH, to see if the origin of this low free chlorine concentrations is in the domestic network.

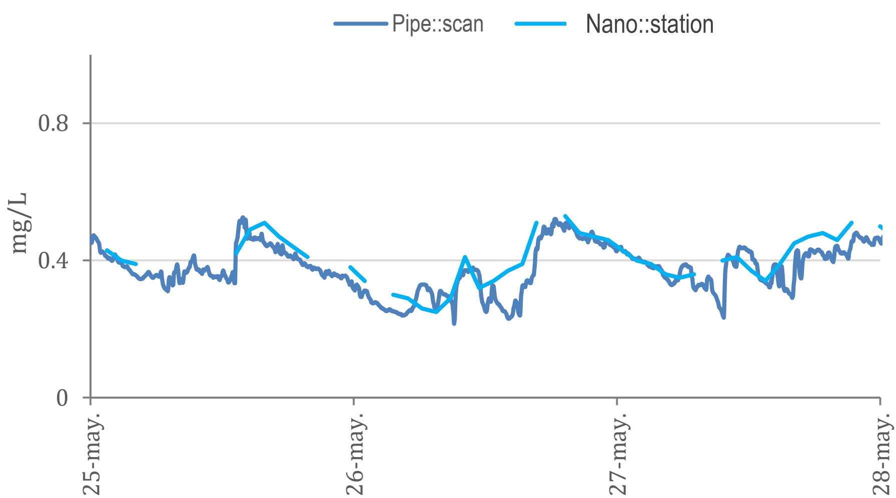


***Graph 5**: This graph shows the same time scale, from May 25 to May 28. The parameters of temperature, pH, conductivity give a similar pattern.*

Except for the low chlorine concentrations, the other three parameters show no alteration and fall within standard values. Beside of that, it can be observed the same daily pattern. These comparative parameters have been used because they are the best for observing a water change.

Since the other parameters show variation that are included within the behaviour of each parameter and do not show any value out of record implies that, the incidence is rejected that the cause of low chlorine concentration is due to an internal incidence of the domestic network.

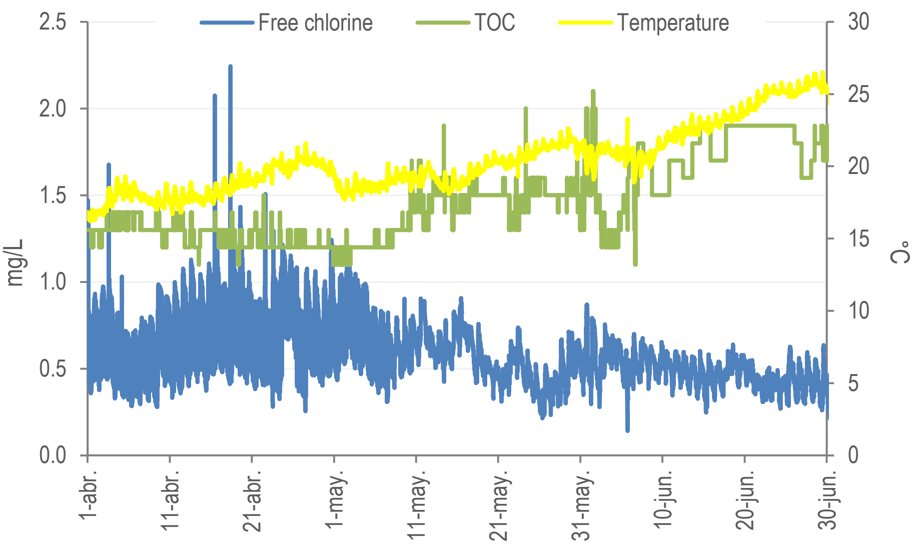
To find out if this is a network problem, the data registered by the pipe::scan (domestic network) is compared with data registered by the nano::station (city network) and it can be seen in Graph 6.



Graph 6 *:Free chlorine parameter registered by pipe::scan versus free chlorine parameter registered by nano::station.. From May 25 to May 28, 2018*

Graphs 6 shows no variation from free chlorine registered at domestic network in comparison with free chlorine registered in the city network. Because of that, this alteration can be related to a network alteration.

To see the behaviour of the network Graph 7 has been created. It shows an increase of temperature during three months along with TOC. TOC and temperature increase during this period. Free chlorine concentration, however, is decreasing.



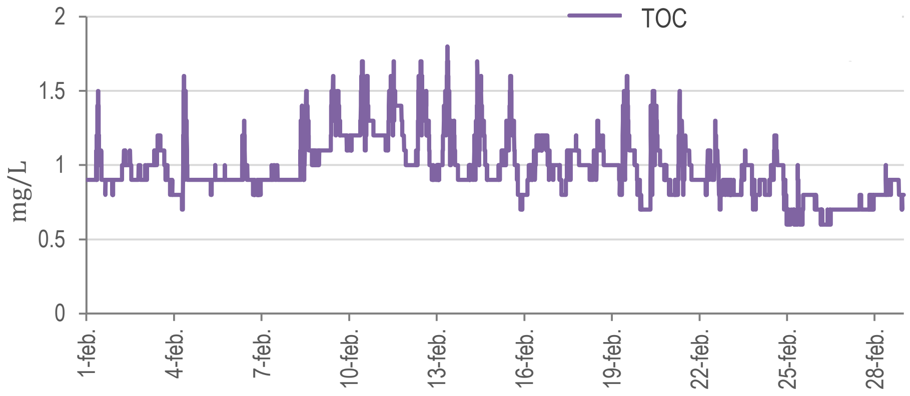
Graph 7: *Record of free chlorine, TOC and temperature behaviour for three months: from March 25 2018 to June 30, 2018. Data recorded by pipe::scan.*

Increasing water temperature promotes bacteriological activity and initiates new reactions. Therefore, TOC concentration is increase at the same time as temperature. Due to these new reactions free chlorine concentration decreases to a limit value.[6]

These low concentrations of chlorine are a phenomenon that happens every year. In late spring, when temperature starts to rise it must be considered that these reactions can occur. Therefore, the treated water must have higher chlorine concentrations, in order to be able to reach quality conditions to users.

5.1.2 TOC peaks due to a water source

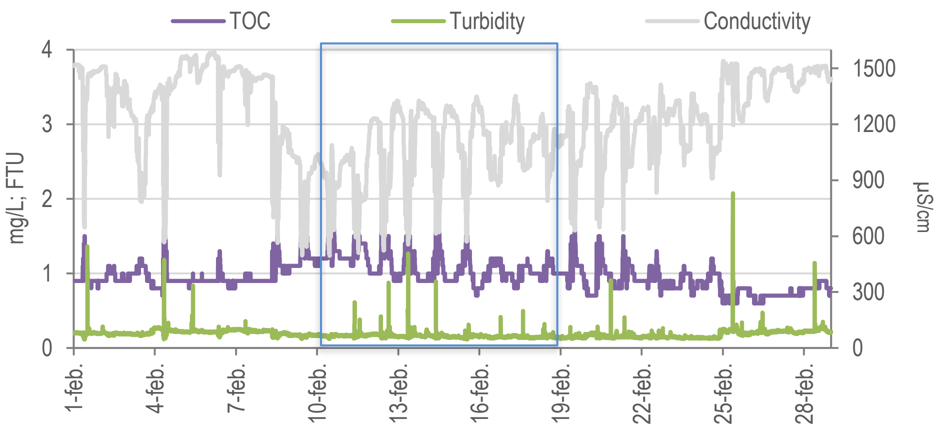
Throughout the month of February, non-normal TOC behaviour is observed.



***Graph 8:** TOC behaviour during February 2019. Data measured by pipe::scan.*

Graph 8 shows how the concentration of TOC is varying according to time of day. It follows oscillations ranging from 0.4 mg/L to 1.8 mg/L.

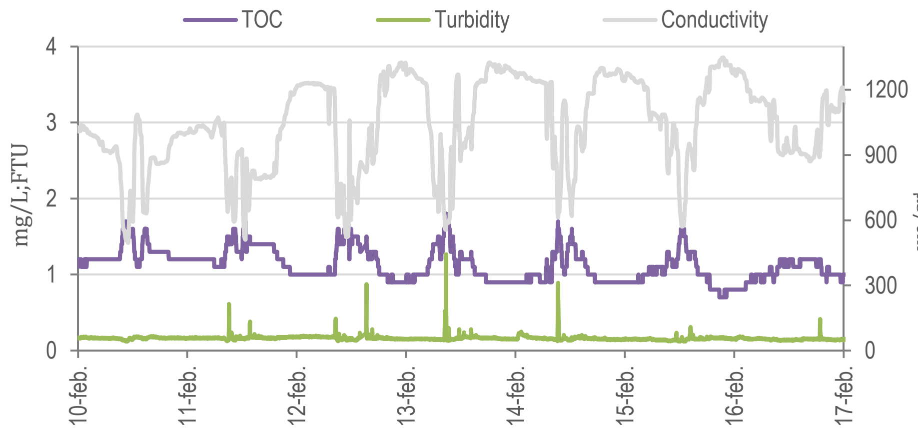
The data of TOC is crossed with turbidity, conductivity and colour analysed by the same sensor inside the building. Graph is obtained:



Graph 9: The graph shows conductivity, free chlorine and turbidity parameters. Data registered by pipe::scan from February 1 to February 28, 2018.

Graph 9 shows three parameters that show significant variations. The conductivity shows strong oscillations. It depends on the time of day, there are values of up 1500 us/cm to minimum values of 500 us/cm. There are also strong oscillations in TOC and turbidity. TOC recorded maximum values of 1.8 mg/L and turbidity records a maximum of 2.1 FTU.

To see more closely the relationship between these three parameters, Graph is presented.



Graph 10*: Conductivity, TOC, and turbidity record from February 10 to February 17, 2018 by the pipe::scan.*

Graph 10 is a detailed section of Graph 9 (blue line). Graph 10 shows a decrease of conductivity that coincides with an increase in TOC. Occasionally, these oscillations of conductivity and TOC are accompanied by peaks of turbidity.

Changes in conductivity are due to a change of water source. If the water comes from Ter River, conductivity marks low values. If the water comes from Llobregat River, conductivity increases. The water source variations cause changes in conductivity and TOC as each water has different characteristics (Table 1 and Table 2).

These water changes occur because the water demand in the sector varies. Depending on the water reserves, Ter water or Llobregat water is sent. Through the reversible pipe it is possible to bring water from the Llobregat to the southern part of the city. Grap 9 shows that during low demand hours, usually at night, there is water from the Ter but when the demand for water increases, it arrives Llobregat water to cover the need of the sector.

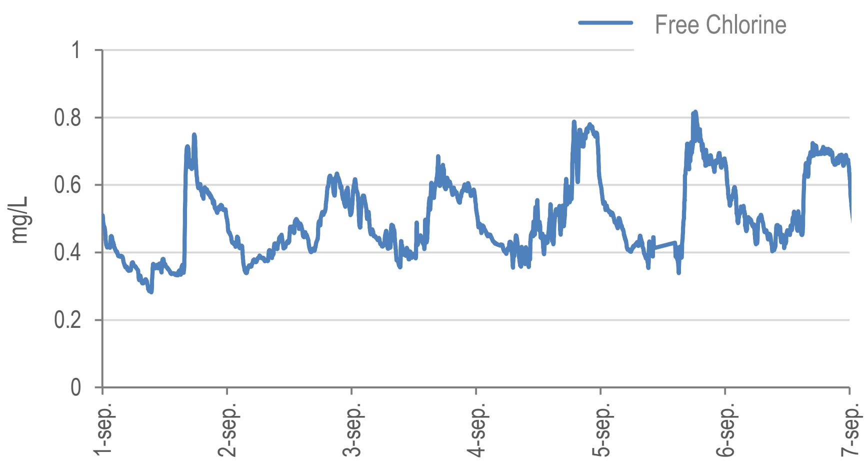
The fact that the water from the Ter arrives at low demand hours and water from the Llobregat during high demand hour is specific to this month, since depending on the weather conditions and water reserves, each month presents its own characteristics. [1]

Detected water conductivity variations can also cause particle drag inside the pipes, for this reason turbidity peaks appear.

5.1.3 Chlorine oscillations due to a change in water demand

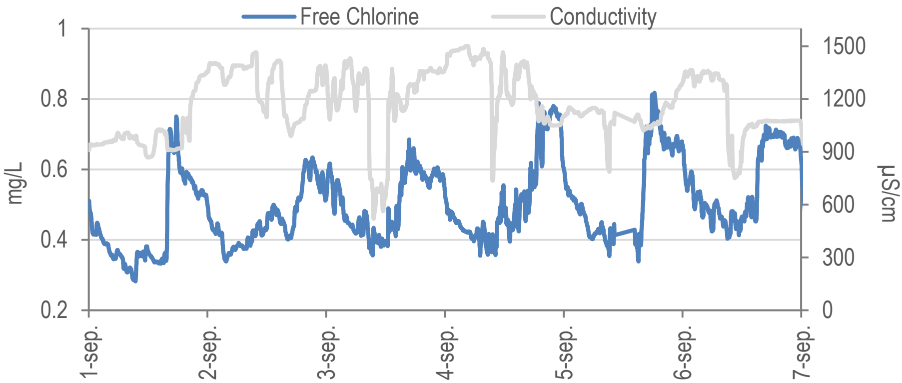
These oscillations in free chlorine concentrations have been observed in different months. Graph 11 shows the month of September because an increase chlorine concentration is very pronounced in a short time.

The chlorine concentrations show oscillations that mark values from 0.3 mg/L to 0.8 mg/L. These peaks all coincide at around 7 p.m. every day.



Graph 11: This graph shows the behaviour of free chlorine from September 1 to September 7, 2018. Data recorded by the pipe::scan.

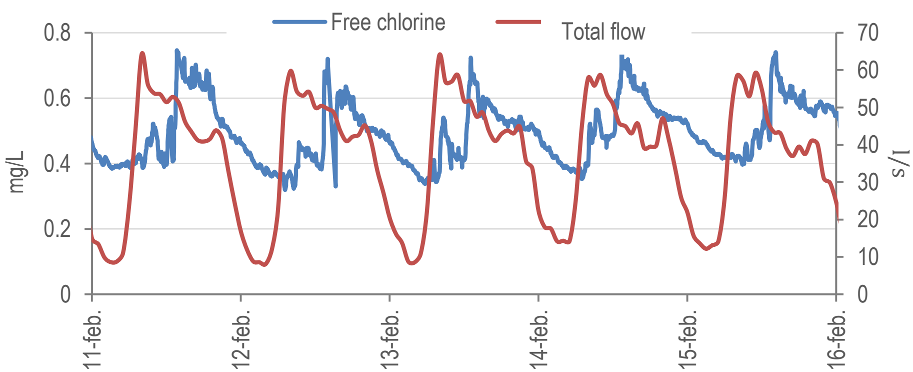
The free chlorine concentration is crossed with conductivity analysed by the same sensor inside the building to see if there is a possible change of water. Graph 12 is obtained:



***Graph 12**: Free chlorine and conductivity behaviour from September 1, 2018 to September 7, 2018. Data recorded by the pipe::scan.*

Graph 12 shows the relationship between free chlorine concentration and conductivity. There is no clear relationship between these two parameters, both follows a different trend.

The concentration of free chlorine is crossed with the flow demand. Water demand is measured at the control points of Llull street and Àlaba street (Figure 6).



***Graph 13:** Water entry from the registered sector at the checkpoints in Llull and Àlaba from September 1 to September 9, 2018. Free chlorine concentration recorded by the pipe::scan over the same time interval.*

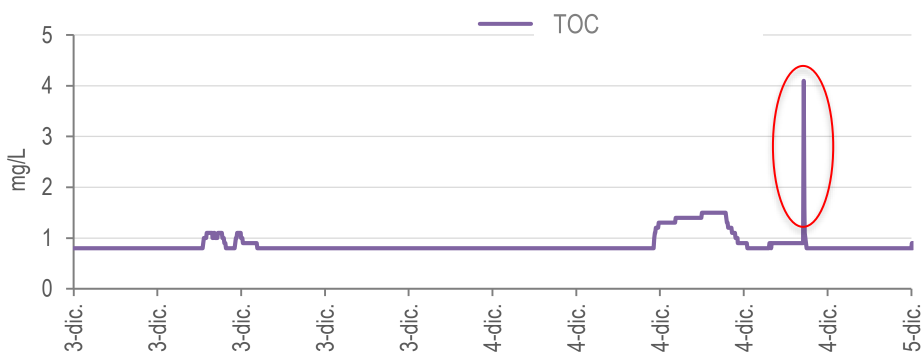
Graph 13 shows the relationship between free chlorine concentration and the water demand in Llacuna sector. Both parameters show the same behaviour. However, chlorine peaks appear hours later than the flow peaks. This occurs because the sensor is placed at a certain distance from the control point and therefore the hours of maximum demand do not coincide in the graph. For this reason, an hourly shift appears in the graph.

There are hours of the day where the demand for the sector is higher. In the morning there is more water expenditure than at night, as there are more people using it. When the water demand is high, the two control points are opened, and the concentration of chlorine is high. The residence time in a distribution network influences [6]. The longer the water passes inside the pipe, the more chlorine is consumed since the biological activity increases. Consequently, the chlorine concentration decreases.

5.2 DOMESTIC EVENTS

5.2.1 Change of flow

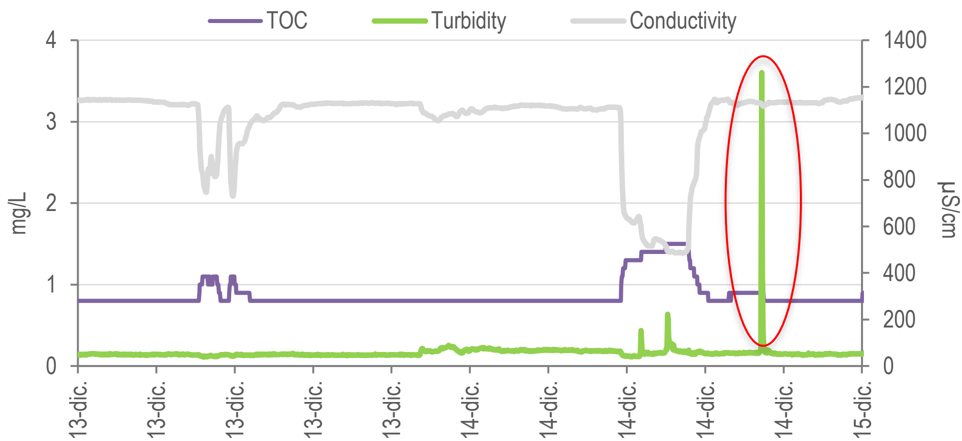
During the month of December, a peak of TOC is observed. It registers a very high value of 4 mg/L. Graph 14 shows this punctual event that occurred on December 14.



Graph 14: *TOC concentration recorded by pipe::scan from December 13 to December 15,2018.*

The TOC has a concentration of 0.9 mg/L except three points. In this section, only the last increase is analysed since the other two do not come out of the standard values marked by TOC.

Graph 15 shows the TOC parameter compared with colour, turbidity and conductivity.



Graph15: *Conductivity, TOC, colour and temperature record from December 13 to December 15, 2018 by the pipe::scan*

There is a decrease in the conductivity of 1100 up to 500 µS/cm. This is due to a change of water. In 1100 µS/cm there is Llobregat water, and there is a water entrance from the Ter. A few hours later, the TOC peak occurs (red circle).

However, in the analysed peak, no change in conductivity is observed but turbidity and colour parameters also mark very high values.

Table 7 shows all the parameters registered every two minutes by the pipe::scan:

At 17:48 the flow shows a drop of up to 0.6 L/h, when this parameter usually registered 15 L/h. Just after this fall the parameters of TOC, colour and turbidity are affected.

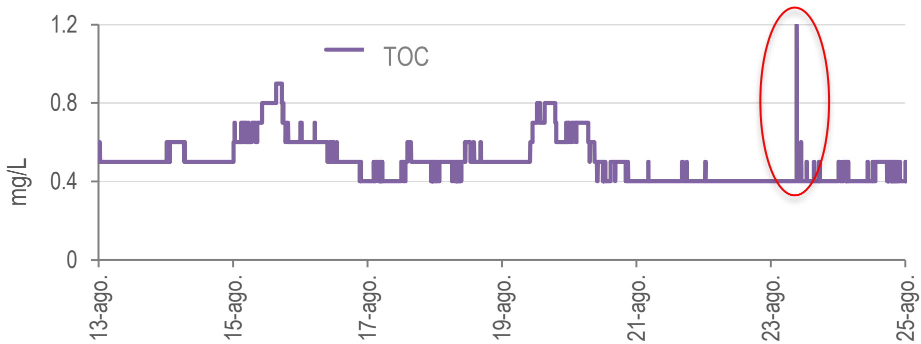
This variation in the flow is due to an internal impact of the building. It could be a pipe obstruction caused by internal drag, an aperture of a tap or a sensor error.

Table 7: *Fragment of data extracted from the pipe::scan log. Data recorded every two minutes in the water that circulates in the office of S::can at Street Ciutat de Granada*

Date/Hour		Free Cl	Flow	Pressure	pH	Cond	Turb	TOC	Colour	T
14–12–2018	17:38	0.709	15.1	4.47	7.51	1131	0.169	0.9	1.9	15.1
	17:40	0.704	15.1	4.46	7.51	1131	0.154	0.9	1.9	15.1
	17:42	0.696	15.0	4.54	7.51	1131	0.158	0.9	1.9	15.1
	17:48	0.444	0.6	4.45	7.49	1130	0.192	0.9	2.0	15.2
	17:50	0.684	15.2	4.32	7.50	1126	1.062	4.1	46.4	15.2
	17:52	0.676	15.2	4.33	7.51	1124	3.602	1.6	12.8	15.2
	17:54	0.679	15.0	4.43	7.51	1123	1.092	1.1	5.6	15.2
	17:56	0.640	15.2	4.39	7.51	1116	0.403	1.0	3.5	15.2
	17:58	0.609	15.2	4.34	7.51	1117	0.326	0.9	2.6	15.2
	18:00	0.613	15.1	4.39	7.51	1118	0.231	0.8	2.1	15.0
	18:02	0.610	15.2	4.43	7.51	1120	0.188	0.8	2.0	14.9
	18:04	0.601	15.1	4.43	7.51	1123	0.168	0.8	1.9	14.8
	18:06	0.589	15.2	4.46	7.51	1123	0.167	0.8	1.9	14.7

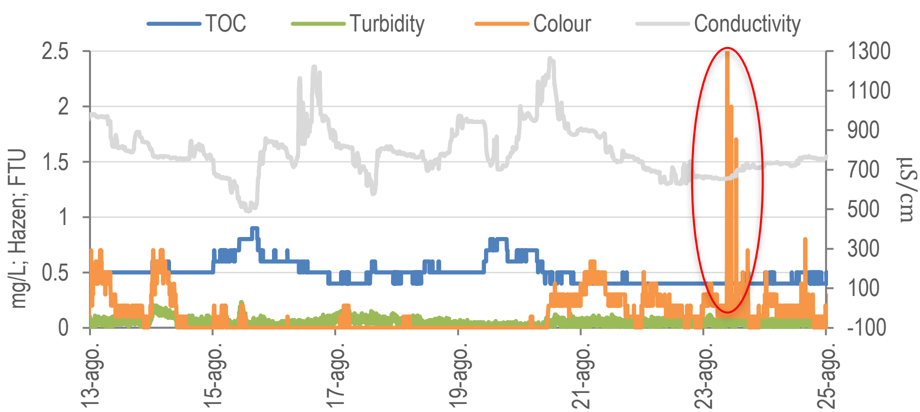
5.2.2 Change of pressure

During the month of August, three increases in the TOC concentration are observed. The first two, will not be analysed since they mark concentration values within the TOC parameters. The last peak appears, on the 23rd at 12 noon where a maximum value of 1.2 mg/L is recorded. Appears in a red circle in Graph 16.



Graph 16: *TOC concentration recorded by pipe::scan from August13 to August 25,2018*

The data of TOC is crossed with turbidity, conductivity and colour analysed by the same sensor inside the building. Graph 17 shows the behaviours of these parameters.



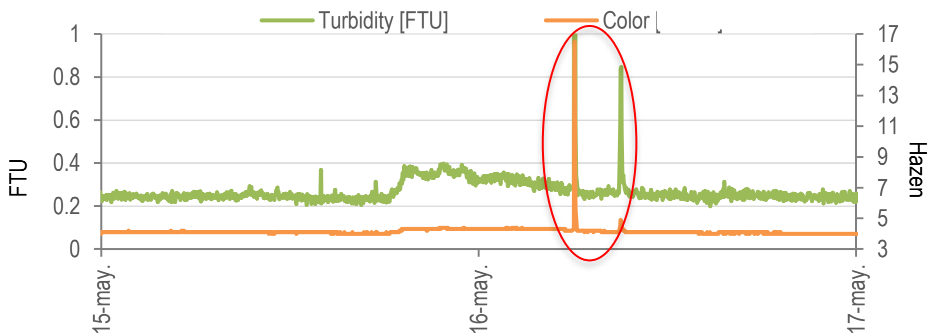
Graph 17: *Conductivity, TOC, colour and temperature parameters recorded from August13 to August 25, 2018 extracted from pipe::scan*

It is observed that in the strong peak of the TOC there is also a turbidity peak and a colour peak. Just at the analysed point (red circle), conductivity shows no variation.

Table 8 shows all the parameters registered in this time interval. The pressure is usually at 4 bars. There is a pressure drop at 9:16 a.m. where the pressure marks a value of 3.58 bars. Two minutes before colour, turbidity and TOC parameters are altered. The changes in these parameters are because there are incidences with inlet pressure to the system.

5.2.1 Dragging

On May 15 there was a turbidity peak. This parameter is compared with colour in Graph 18:



Graph 18: *Colour and turbidity record from May 15 to May 17, 2019 by the pipe::scan*

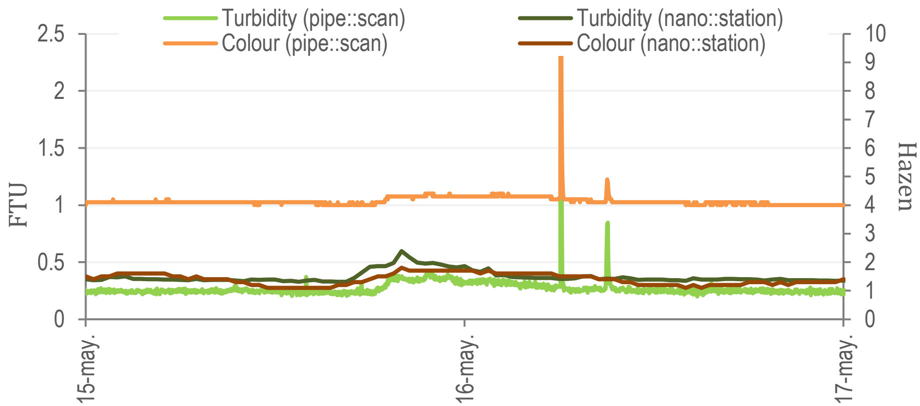
In Graph 18 it is observed that turbidity increases at 7 p.m. and that it does not recover the value until 5 a.m. The colour shows a fair pitch when turbidity regains the value. On Day 16 at 9:36 a.m., both parameters colour and turbidity show a peak.

The data from the pipe::scan are crossed with the data from the nano::station to see if this increase in turbidity and colour also occurs in the city network.

Graph 19 shows both parameters registered by pipe::scan have an increase. Colour and turbidity registered by the Nano::station do not show any variation

Table 8: *Fragment of data extracted from the pipe::scan log. Data recorded every two minutes in the water that circulates in the office of S::can at Street Ciutat de Granada*

Date	Hour	Free Cl	Flow	Pressure	pH	Cond	Turb	TOC	Colour	T
23–08–2018	9:10	0.456	15.2	4.38	7.41	655	0.06	0.4	0.1	26.7
	9:12	0.459	15.1	4.40	7.41	655	0.04	0.4	0.1	26.8
	9:14	0.454	15.2	4.24	7.41	655	1.71	0.7	4.3	26.8
	9:16	0.443	15.2	3.58	7.41	657	3.48	0.8	5.7	26.8
	9:18	0.449	15.2	4.40	7.41	655	6.93	1.2	13.9	26.8
	9:20	0.459	15.2	4.38	7.41	654	2.74	0.8	6.1	26.7
	9:22	0.465	15.2	4.36	7.41	655	1.70	0.6	3.9	26.7
	9:24	0.469	15.2	4.26	7.41	656	1.44	0.6	3.4	26.7
	9:26	0.475	15.0	4.34	7.42	656	0.73	0.5	2.4	26.7
	9:28	0.477	15.2	4.38	7.42	656	0.39	0.4	0.8	26.7
	9:30	0.475	15.2	4.43	7.41	656	0.22	0.4	0.4	26.7
	9:32	0.476	15.3	4.41	7.42	656	0.16	0.4	0.3	26.7
	9:34	0.589	15.3	4.29	7.42	656	0.07	0.4	0.3	26.7
	9:36	0.478	15.2	4.31	7.42	656	0.10	0.4	0.3	26.7



Graph 19: *Colour and turbidity record from May 15 to May 17, 2019 by the pipe::scan compared to colour and turbidity recorded from May 15, to May 17, 2019 by nano station*

Therefore, it can be concluded that there was an internal drag on the building's pipes. These discharges are a consequence of the condition of the pipes and their internal maintenance. There was no drag on the city network at this time interval.

6. CONCLUSIONS

This study analysed the events and categorized them according to whether they occurred within domestic network or city network.

Some conclusions from this study have been drawn from the observation and analysis of the data recorded by the pipe::scan, which corresponds to the domestic network. Other conclusions have been described through study and observation of nano::station, located on a pipe in the city network. This sensor makes possible to know what variations can occur in the city network. Therefore, the conclusions drawn from this study are:

- An increase in temperature causes an increase in microbiological activity in water. This implies and increase in TOC, as there is more carbon in the water and, consequently, a decrease of free chlorine concentration is produced.

    - Due to this temperature change, at the beginning of summer, the minimum levels of chlorine in the city network are reached and have a value of 0.2 mg/l.

- Chlorine concentration depends on the residence time. The higher the residence time, the lower the free chlorine concentration. Therefore, the water demand in the sector and the chlorine concentration are related because in high water consume hours, when the residence time is low, the chlorine concentration will be high.

- The quality of water changes greatly depending on their origin. Each water has its characteristics. Ter and Llobregat water have very different conductivities as well as different TOC values. These changes in water cause alterations in the sensor. As has been observed, these changes in conductivity result in increased TOC, and repeatedly in turbidity and colour.

Some water changes cause internal wiping in the domestic network. When water changes, there is a rapid movement of water inside the pipes which can lead to particle drag. These drags can occur in both, the city network and the domestic network. In this study, domestic network drags have been observed and the following conclusions have been drawn:

- Flow alterations are caused by a blockage in the pipe or a stop in the system. These changes cause an increase in the parameters of colour, TOC and turbidity.

- A change in pressure are caused by a blockage in the pipe or an opening of another tap in the building. These changes cause an alteration on colour, TOC and turbidity parameters.

- Most drags occur on the domestic network, as pipe conditions are not ideal. When a drag occurs into the city network, it is usually detected by users as it easily reaches the domestic network.

Thanks to this investigation it is possible to know if the incidents recorded by the pipe::scan sensor have a serious impact in the drinking water quality that Aigües de Barcelona distributes, and it gives us an important and intrinsic overview of what kind of water population drinks.

7. REFERENCES AND NOTES

[1] S. Platikanov, V. Garcia, E. Landeros, R. Devesa, L. Matía, and R. Tauler, “Determination of water supply sources in the Barcelona distribution system by UV spectrophotometry and PLS,” *Water Sci. Technol. Water Supply*, vol. 11, no. 1, pp. 45–54, 2011.

[2] F. J. Y. Moreno, “Planificación de la red de abastecimiento.” Universitat Politecnica de Catalunya, Barcelona, p. 26, 2011.

[3] F. J. Y. Moreno, “Sectores de consumo,”Universitat Politecnica de Catalunya, Barcelona, 2011.

[4] R. Ingenier, “Los sensores químicos y su utilidad en el control de gases contaminantes The chemical sensors and their utility in the monitoring of polluting gases,” vol. 19, pp. 74–88, 2012.

[5] R. Kumar and R. Singh, *Prospect of Graphene for Use as Sensors in Miniaturized and Biomedical Sensing Devices*. Elsevier Ltd., 2018.

[6] J. Machell and J. Boxall, “Modeling and field work to investigate the relationship between age and quality of tap water,” *J. Water Resour. Plan. Manag.*, vol. 140, no. 9, 2014.

[7] Aigües de Barcelona (2019), Fonts d’Abastament. Aigües de Barcelona, Barcelona, Spain. Information extracted from https://www.aiguesdebarcelona.cat/ca/l-aigua-teva-ciutat/com-es-gestiona-laigua/fonts-d-abastament

[8] Gueguen, F., Sanz, A., Langlais, C., Bonnelye, V., Creme, G., DelCampo, I. & Beltran, F.2008Barcelona Desalination Plant:200.000 m3/day of Drinking Water. Proceedings of the IWAWorld Water Congress and Exhibition. Vienna (Austria).

[9] Spellman, F.2007The science of water. Concepts and Applications.CRC Press, Taylor and Francis

8. ACRONYMS

DP: Desalination Plant

DWTP: Drinking Water Treatment Plant

FTU: Formazin Turbidity Unit

TOC: Total Organic Carbon

PLC: Power Line Communication

APPENDICES

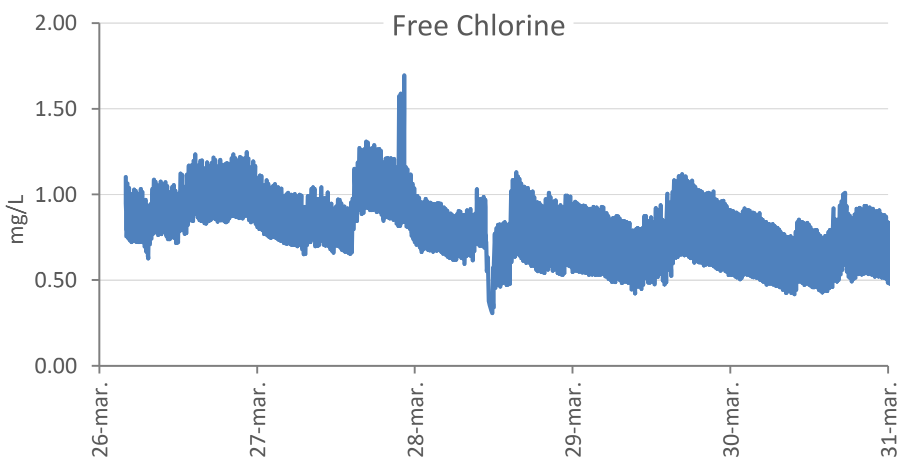
9. APPENDIX 1: MONTHLY COMPARATION

This study was based on the previous analysis on each detected event. All the events and their analysis can be read in these annexes The pipe::scan is a sensor that records data every 2 minutes. When this study began, it had stored more than a year of information. What has been done is graphed monthly for free chlorine and TOC parameters to see which patterns follow. In these monthly analyses, alterations were recorded that subsequently analysed as punctual events. These events are discussed and explained in Annex 2.

9.1 DESCRIPTION AND COMPARATIVE

9.1.1 Free Chlorine (pipe::scan)

<u>March 2018</u>



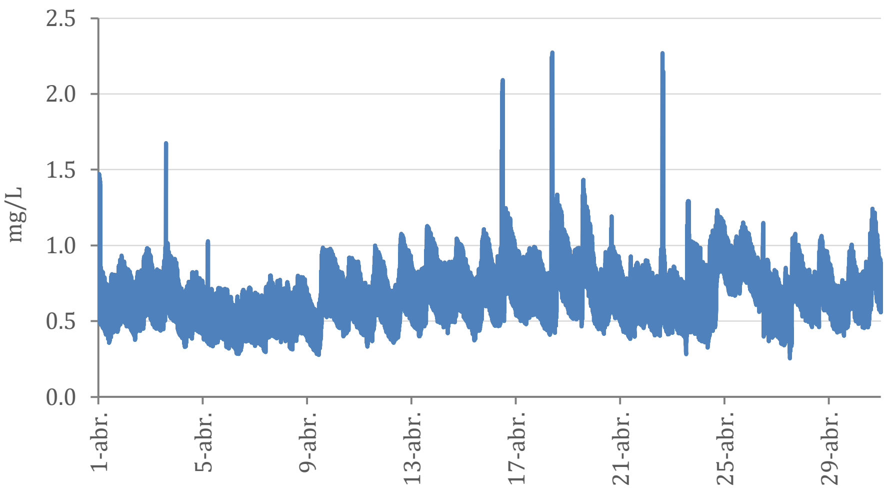
Graph A.1: *Free chlorine recorded by pipe::scan from march 26 to march 31 2018*

The values of free chlorine during the month of March range from values of a minimum of 0.3 to a maximum value of 1.7 mg/L. A daily pattern is observed: at 9-10 in the morning there is a rise of chlorine, during the day it is decreasing until the night when the parameter reaches the minimum value. Graphic 1 shows a peak during day 27 at 22:23 which reaches 1,6 mg/L (very high value). This event will be analysed as event 1 in annex 2

Increases and decreases in the value of the chlorine concentration are due to the water demand in the area. When demand is high the water comes directly from the plant and has high chlorine concentrations. Otherwise, if the demand is low, the water remains on the pipes and loses its chlorine.

This trend is observed every month of the year.

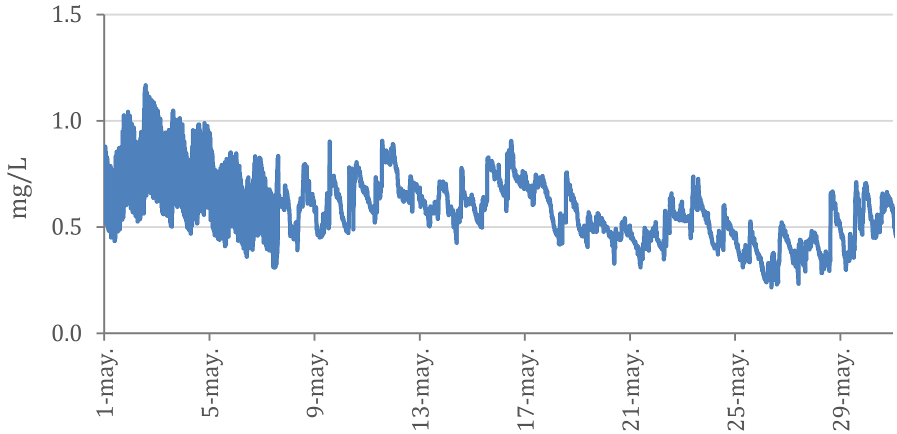
<u>April 2018</u>



Graph A.2: *Free chlorine recorded by pipe::scan from April 1 to April 30 2018*

The value of chlorine during April follow the pattern mentioned in Graph A.1. In Graph A.2, there are very high chlorine values in 8 occasions. The highest value registered is higher than 2.20 mg/L. It exceeds the maximum allowable concentration on the distribution system. These values will be analysed as event 2 in the study 2

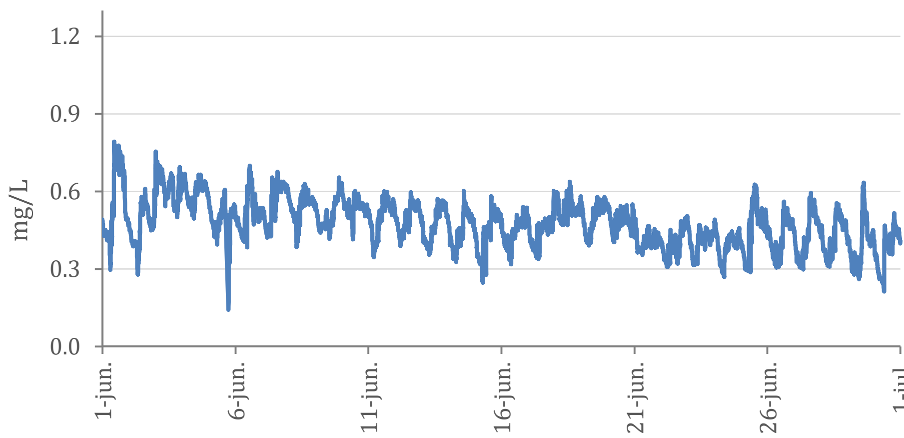
May 2018



Graph A.3: *Free chlorine recorded by pipe::scan from May 1 to May 31 2018*

In Graph A.3 it can be seen at the beginning of the month there is more dispersion in the values. The first weeks of May have a higher concentration of chlorine (around 0.5 and 1.1 mg/L) while from day 9, the concentration of free chlorine decreases to a minimum of 0.2 mg/L. We observe the same pattern during the whole month: an increment of chlorine concentration at the beginning of the day and decrease during the night.

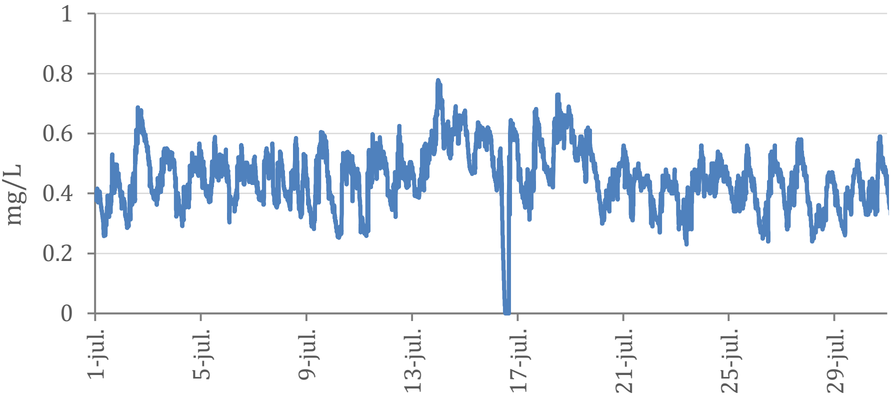
June 2018



Graph A.4*: Free chlorine recorded by pipe::scan from June 1 to July 1 2018*

In Graph A.4 it can be seen how the value of chlorine is more stabilized. The periodicities are still observed during the day where there is a peak in the first hours of the day and then there is a decrease. A concentration drop appears on day 6. During the rest of the month no anomaly is observed.

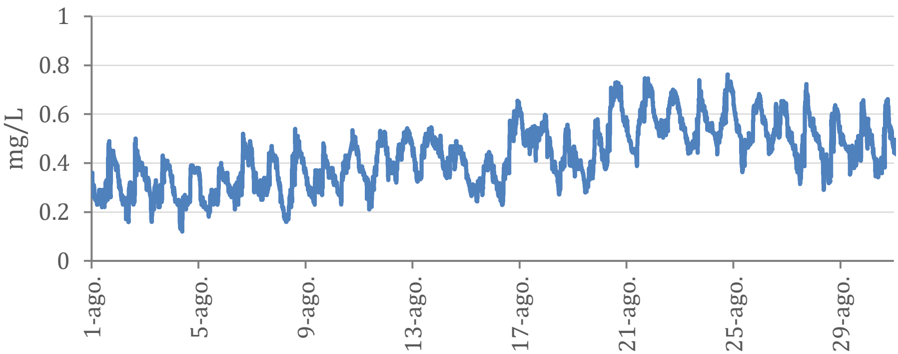
July 2018



Graph A.5: *Free chlorine recorded by pipe::scan from July 1 to July 31 2018*

In Graph A.5 it can be seen an anomaly on the 16th where there is a chlorine drop that reaches the 0 and slowly regains the value. It will be analysed as event 3 in Annex 2. Except for this disturbance, it can be observed a certain frequency with the values with peaks that reach maximum values of 0.7 mg/L and 0.8 mg/L and minimum values of 0.2 and 0.3 mg/L.

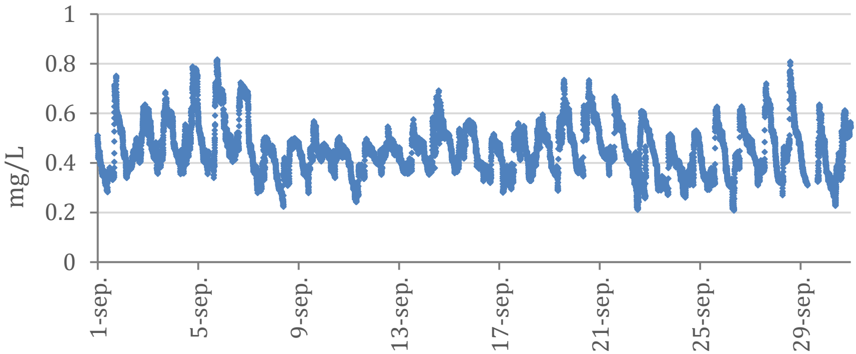
August 2018



Graph A.6: *Free chlorine recorded by pipe::scan from August 1 to August 31 2018*

At the beginning of the month, the concentration of free chlorine is between 0.5 mg/L at the highest points (coincides with early morning hours) and 0.15 mg/L at the lowest points (coincides with the night time). As of the second fortnight, growth is observed and the concentration reaches higher values ranging from 0.75 mg/L at the highest points (first hours of the day) to minimum values of 0.3 mg/L. No disturbances or points are observed in graph A.6.

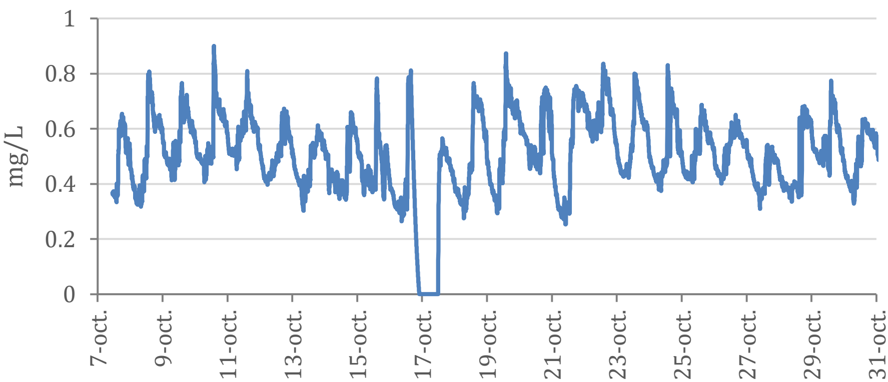
September 2018



Graph A.7: *Free chlorine recorded by pipe::scan from September 1 to September 30 2018*

In Graph A.7 it can be seen how the chlorine concentration remained relatively stable, marking maximum values of 0.8 mg/L and minimum values of 0.2 mg/L. No outliers are observed.
It repeats the same patterns as graphics presented above

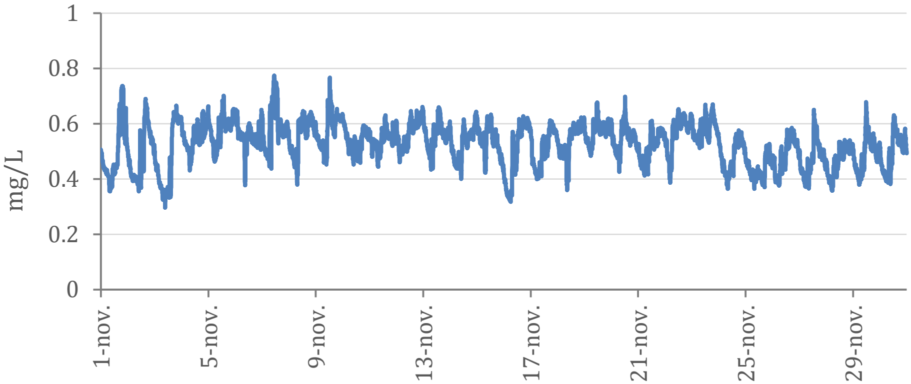
October 2018



Graph A.8: *Free chlorine recorded by pipe::scan from October 7 to October 31 2018*

Graph A.8 shows a disturbance lasting on day 16 where there is a sharp decrease in the concentration of chlorine until it reaches 0 for a few hours. Slowly recover the value of the chlorine concentration and from the 18th day the value ranges from 0.9 mg/L in the maximum to 0.25 mg/L in the minimum. That will be analysed as event. The values are observed periodically.

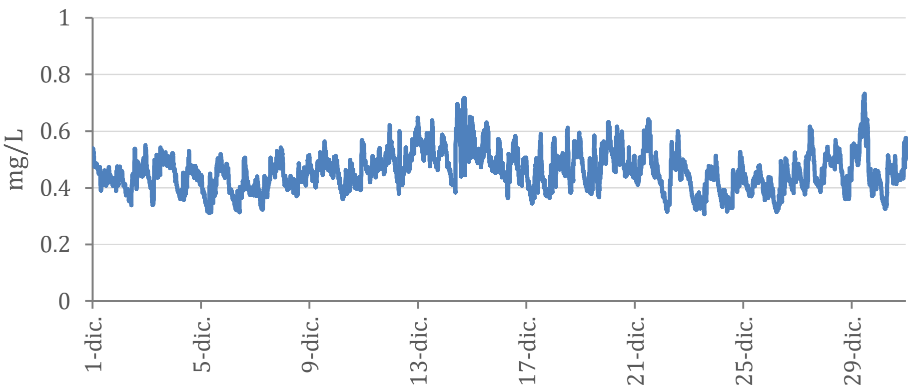
November 2018



Graph A.9: *Free chlorine recorded by pipe::scan from November 1 to November 30 2018*

Graph A.9 shows No disturbance during the month of November. The data follows a period where maximum values appear at the first hours of the day and minimum values at night. The highest value is 0.78 mg/L (November 8) and the minimum value is 0.3 mg/L (November 3). There is no value that sets a value out of range.

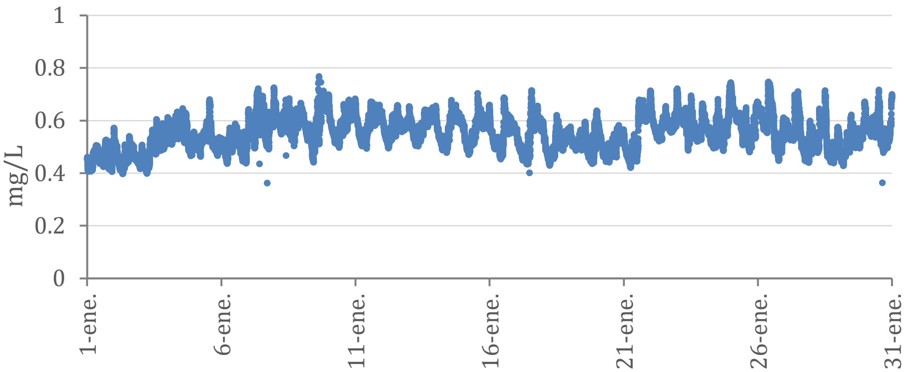
December 2018



Graph A.10: *Free chlorine recorded by pipe::scan from December 1 to December 31 2018*

Graph A.10 have the same analysis as Graph A.9. It can be seen a regularity in the data. A maximum value appears at the end of month (0.72 mg/L). During the whole month the concentration varies between values of 0.3 and 0.6 mg/L. As in the other months, increases are observed at the beginning of the day and decreases during the night.

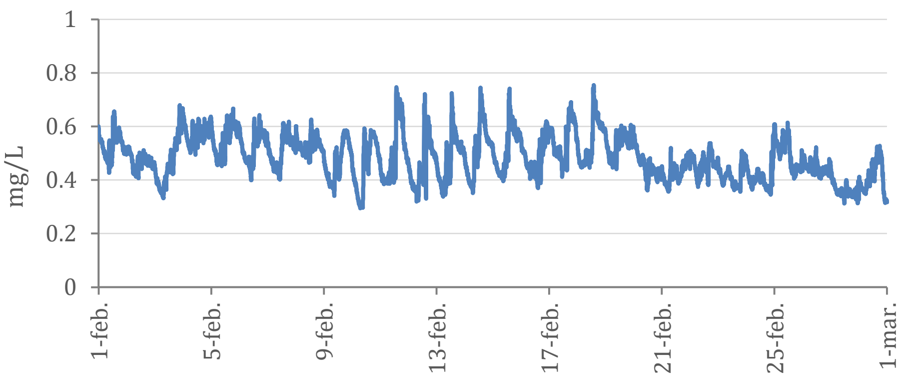
<u>January 2019</u>



Graph A.11: *Free chlorine recorded by pipe::scan from January1 to January 31 2019*

Graph A.11 shows very slight growth of free chlorine concentration. At the beginning of the month there are maximum values of 0.65-0.7 mg/L and at the end of the month the maximum value is 0.75 mg/L. 5 points are observed that do not follow the same behaviour as the rest. They have minimum values. Punctual points appear below. They can be considered as outliers values.

<u>February 2019</u>

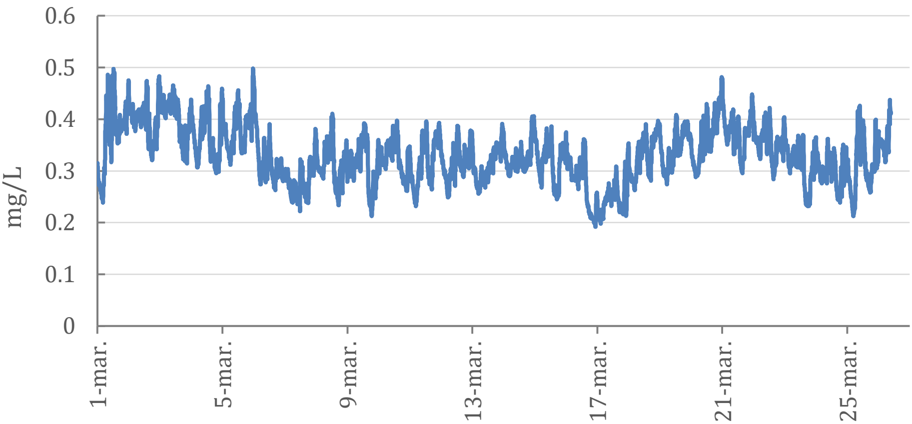


Graph A.12: *Free chlorine recorded by pipe::scan from February 1 to March 1 2019*

Graph A.21 shows an anomalous behaviour of free chlorine from day 12 to 17. There are very high peaks and then a strong decrease (the values range from 0.73 to 0.35 mg/L). This behaviour was only observed during this time period. Theses peaks will be analysed as event in annex 2.

The rest of the month passes normally, except for a high concentration increment on February 3.

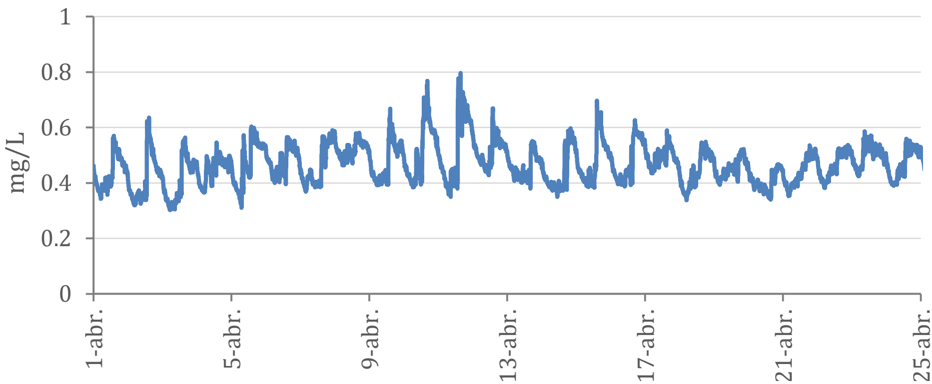
March 2019



Graph A.13: *Free chlorine recorded by pipe::scan from February 1 to March 1 2019*

Graph A.13 shows an increase in concentration in the first weeks, where the values range from 0.25 to 0.5 mg/L. It stabilizes the concentration at day 7, it moves in the ranks of 0.25 and 0.4 mg/L. There is a decrease on day 17 but returns to recover the value at the end of the month.

April 2019



Graph A.14: *Free chlorine recorded by pipe::scan from April 1 to April 25 2019*

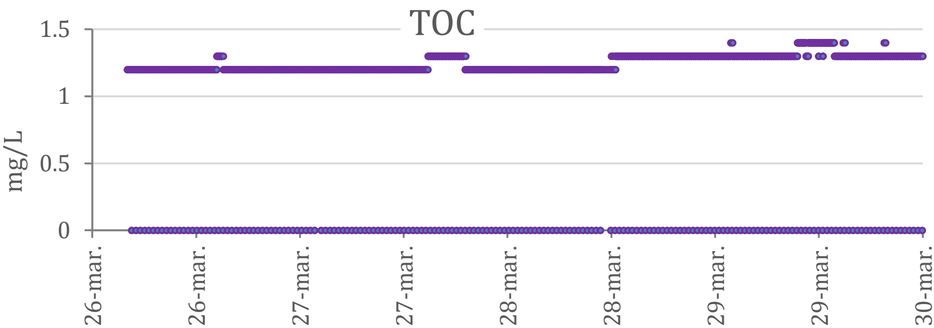
Graph A.14 shows the typical behaviour of free chlorine. There are increases and decreases in the concentration. The highest registered value is 0.8 mg/L and the lowest of 0.3 mg/L. No behaviour out of ordinary is observed.

9.1.2 Total Organic Carbon (pipe::scan)

Total organic carbon, from now TOC

March 2018

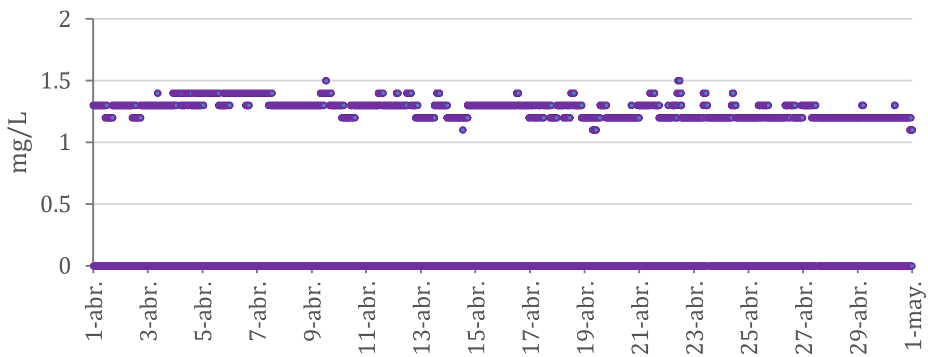
**Each 27 values show NaN values, for that reason the line at 0.*



Graph A.15: *TOC recorded by pipe::scan from March 26 to March 30 2018*

It can be observed that in graph A.15 the variation of TOC is minimum. The concentration goes from 1.2 to 1.4 mg/L. Values vary only two tenths.

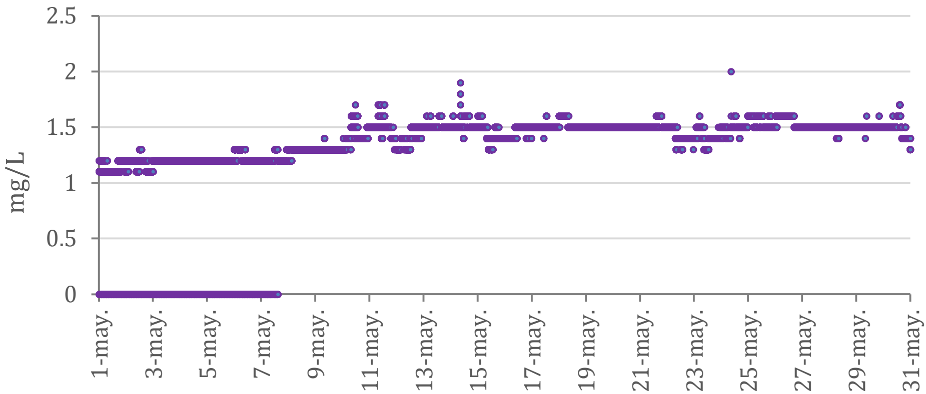
April 2018



Graph A.16: *TOC recorded by pipe::scan from April 1 to May 1 2018*

Graph A.16 shows that during the month of April, the value of TOC does not change significantly. It takes values from 1.2 to 1.4 mg/L. Variations do not follow any pattern. Two measures appear above 1.4 mg/L and three measures below 1.2 mg/L.

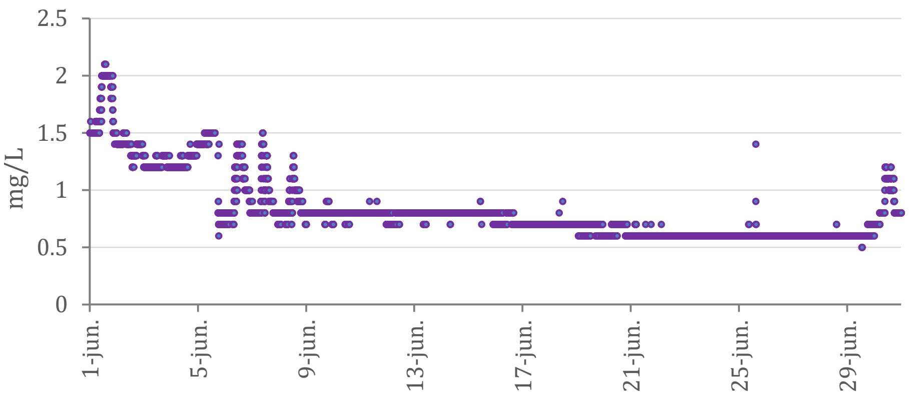
May 2018



Graph A.17: *TOC recorded by pipe::scan from May 1 to May 31 2018 From this month, the NaN data no longer appears.*

Graph A.17 shows that at the beginning of the month the concentration registers values of 1.1 – 1.2 mg/L and from day 9/10 the TOC values registers values of 1.3 – 1.4 mg/L. There is an increase in TOC and three peaks appear. There is a punctual concentration of 2 mg/l.

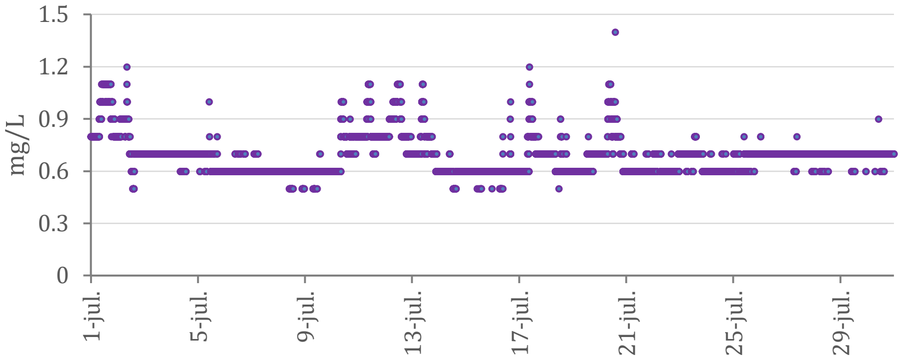
June 2018



Graph A.18: *TOC recorded by pipe::scan from June 1 to June 30 2018*

Graph A.18 begins with high values of TOC, which vary from 1.5 to 2.1 mg/L. The concentration is decreasing (with small peaks) until day 9 that stabilizes to 0.8 mg/L. At mind-month it decreased to 0.7 mg/L and at the end of the month it stabilized at 0.6 mg/L. The last day of the month there is a peak that goes from 0.6 to 1.2 mg/L.

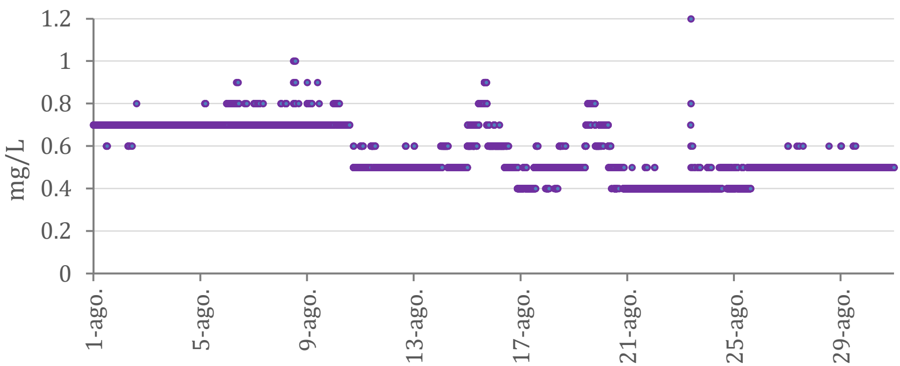
July 2018



Graph A.19: *TOC recorded by pipe::scan from July 1 to July 31 2018*

In Graph A.19 it can be observed that TOC takes values from 0.6 to 0.8 mg/L mostly (some values appear at 0.5 mg/L). Different peaks are seen, but those that seem to be interesting to analyse are: one that TOC reaches a concentration of 1.6 mg/L (punctual value) and another peak that the concentration has a value of 1.4 mg/L. These two points are those that show a greater variation in a smaller time interval. The other peaks the variation is little.

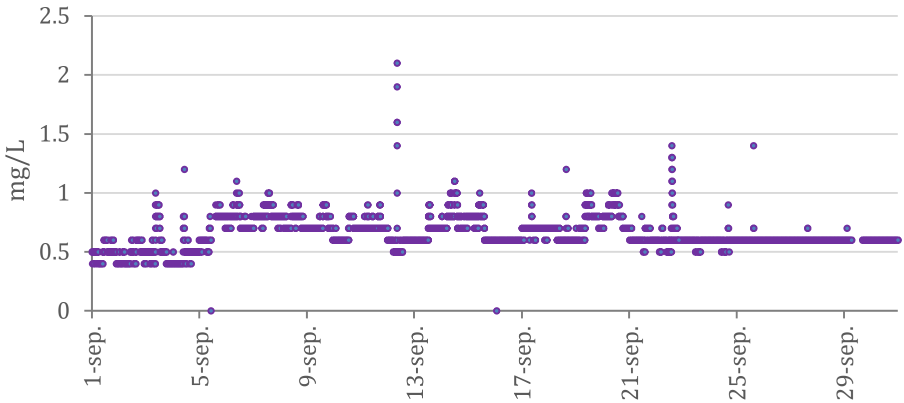
August 2018



Graph A.20: *TOC recorded by pipe::scan from August 1 to August 31 2018*

In Graph 20 it can be seen how the value of TOC is 0.7 mg/L the beginning of the month. On august 11 this value decreases to 0.5 mg/L. Some peaks can be observed, the most pronounced has a value of 1.2 mg/L. There is no value that comes out of the limits.

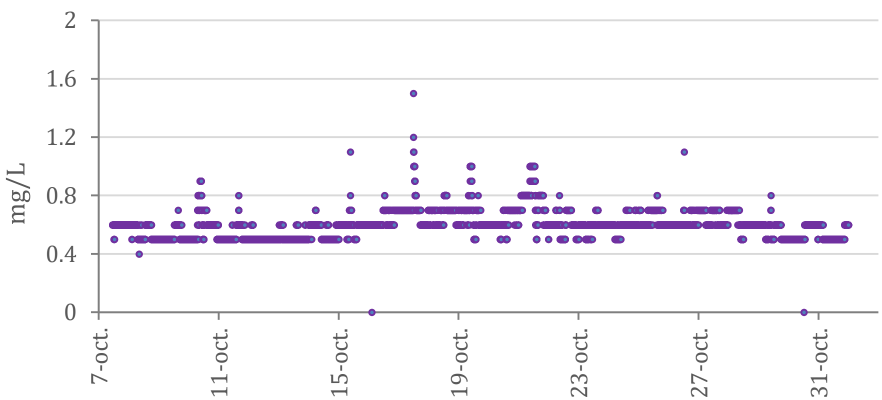
September 2018



Graph A.21: *TOC recorded by pipe::scan from September 1 to October 1 2018*

During September the concentration takes values from 0.5 to 1 mg/L. Graph A.20 shows different peaks that appear throughout the month. The most important have a value of 2.1 mg/L. Other important peak that appears have a value of 1.4 mg/L.

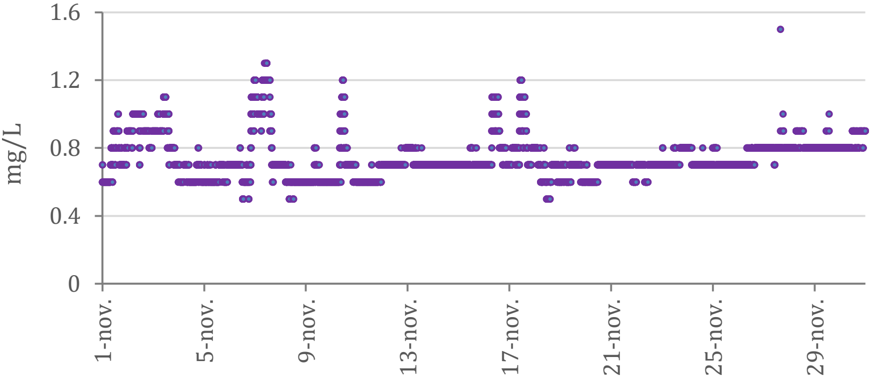
October 2018



Graph A.22: *TOC recorded by pipe::scan from October 1 to November 2 2018*

The TOC value remains constant during the month of October (values between 0.5 and 0.8 mg/L). A peak appears on day 17 where TOC has a value of 2.6 mg/L. This value goes out of bounds.

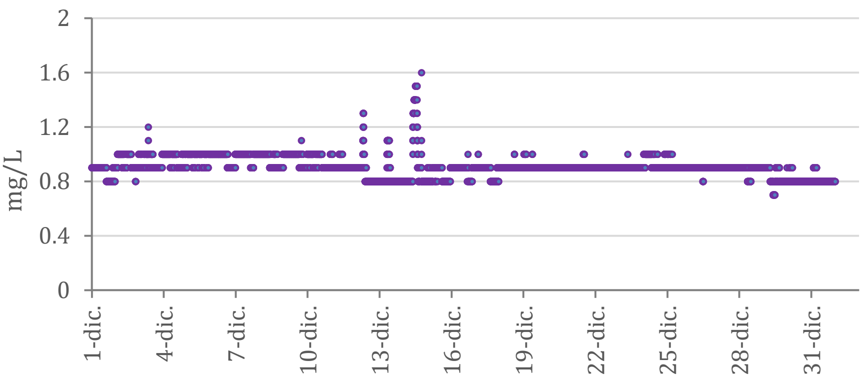
November 2018



Graph A.23: *TOC recorded by pipe::scan from November 1 to December 1 2018*

Graph A.23 show some peaks. The value of TOC is maintained between 0.6 and 0.8 mg/L. The first peak appears at the beginning of the month where the concentration moves from 0.6 to 1.1 mg/L. The second peak reaches a value of 1.3 mg/L. The third peak reaches a value of 1.2 mg/L. The fourth peak that appears are two consecutive rises of the concentration, the first one up to 1.1mg/L and the second up to 1.2 mg/L. At the end of the year there is a sporadic value that marks a TOC concentration of 1.5 mg/L.

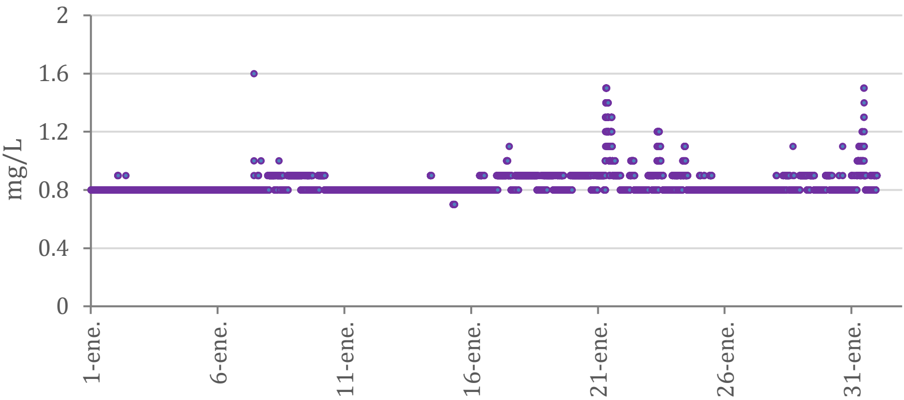
December 2018



Graph A.24: *TOC recorded by pipe::scan from December 1 2018 to January 2 2019*

In December the concentration of TOC is constant at a value of 1 exception of a point that marks a concentration of 4mg/L (This value doesn't appear in the graph A.24).

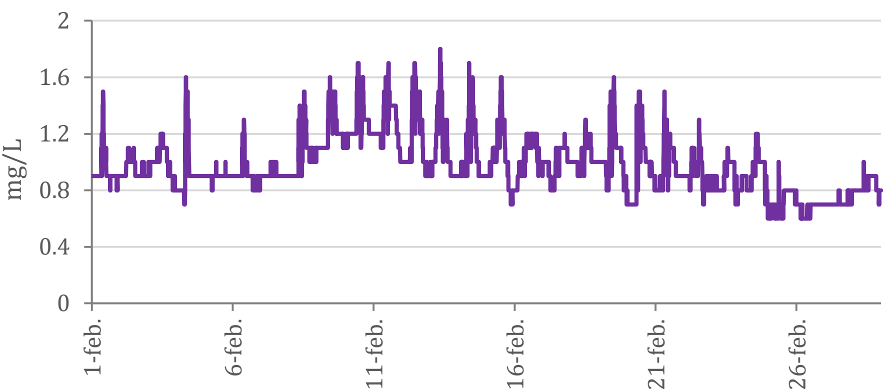
January 2019



Graph A.25: *TOC: recorded by pipe::scan from January 1 to February 2 2019*

Graph A.25 shows that the concentration of TOC is 0.8 mg/L (value that is maintained for most of the time). Several peaks appear: the first one has a punctual value measuring 1.6 mg/L, after that, a few measures appear at 0.9 mg/L and then the concentration returns to the value of 0.8 mg/L. There is an increase in the concentration ranging from 0.8 to 1.5 mg/L on day 21. Then, there is a gradual decrease of the concentration to 0.8 mg/L but two peaks of 1.2 and 1.1 mg/L appear again after this first rise. At the end of the month there is a peak reaching to 1.5mg/L.

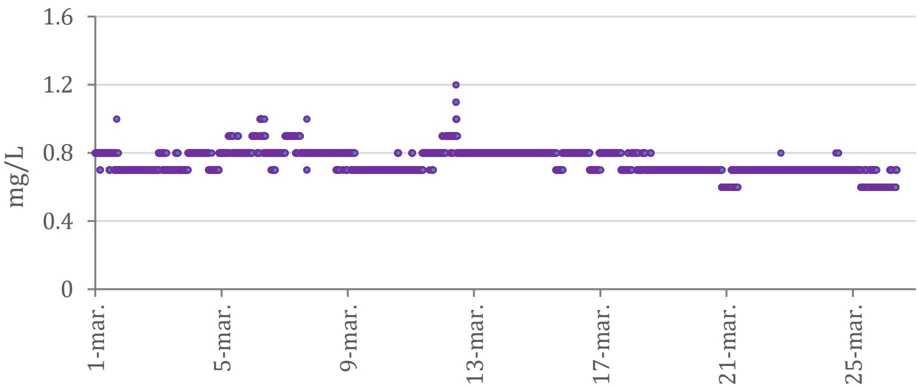
February 2019



Graph A.26: *TOC recorded by pipe::scan from February 1 to March 1 2019*

Graph A.26 shows many variations of TOC concentration. There are oscillations that range from high values of 1.8 mg/L to low values of 0.6 mg/L. It does not stabilize at any time. The oscillations are more pronounced at the middle of the month.

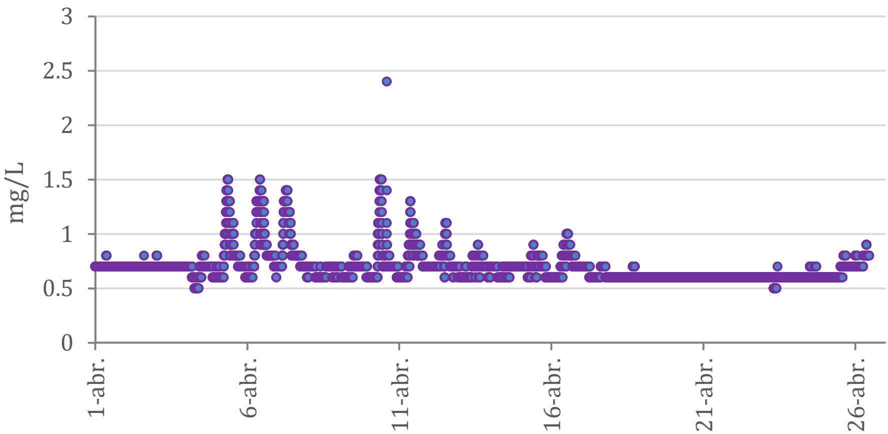
March 2019



Graph A.27: *TOC recorded by pipe::scan from March 1 to Marc 27 2019*

The TOC values during the month of March are quite stable between 0.7 and 0.8 mg/L. A peak where the concentration reaches 1.2 m/L observed on day March 12.

April 2019



Graph A.28: *TOC recorded by pipe::scan from March 1 to Marc 27 2019*

Graph A.28 shows three peaks of approximately the same value at the beginning of the month were observed where maximum values of 1.5 mg/L were recorded. On the 10th, 11th and 12th, four peaks are recorded (the first one with the highest intensities and from there they appear with a lower value each time). From day 17 the value of the TOC does not present any variation.

10. APPENDIX 2: PUNCTUAL EVENTS

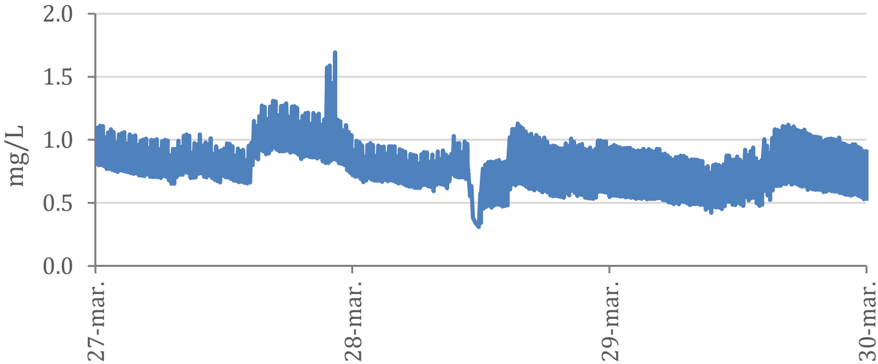
This study shows a deep analysis of all those values detected in the study of monthly free chlorine and TOC behaviour. The graph first shows the parameter values out of range. Then a comparison with parameters also registered by the pipe::scan is shown and finally the reason for the out of range value is explained.

10.1 FREE CHLORINE

Of the annual study of chlorine behaviour, different events have been analysed.

10.1.1 Destabilization of the sensor

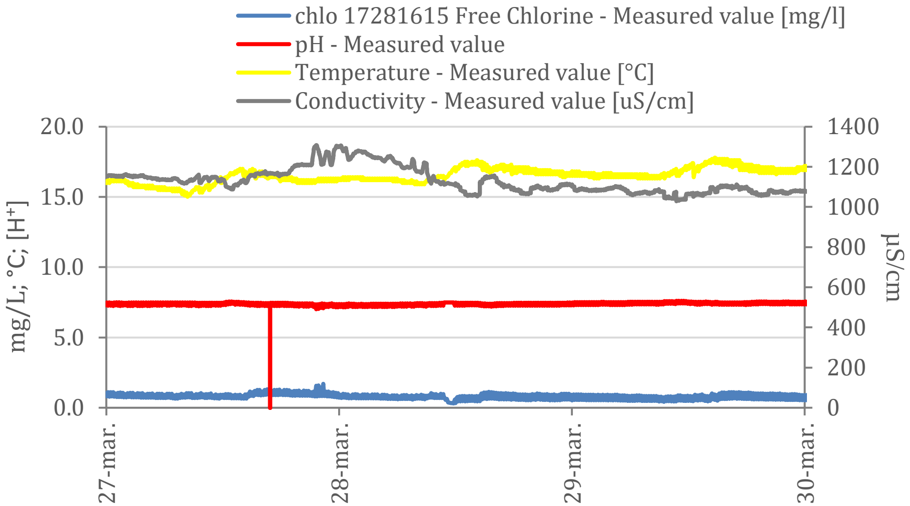
March 2018



Graph A.29: *Free chlorine recorded by pipe::scan from May 27 to May 30 2018*

Graph A.29 shows, high values of TOC concentration. On the 27th at 8 p.m. there is a peak reaching 1.7 mg/L.

If free chlorine is compared with the pH, conductivity and temperature Graph A.30 is obtained:

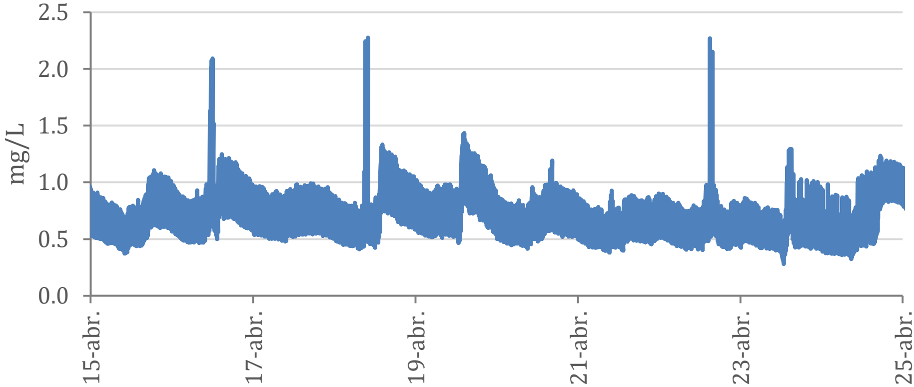


***Graph A.30**:Free Chlorine, pH, temperature and conductivity recorded by the pipe::scan from March 27 to March 30 2018.*

In Graph A.30 it can be seen how the pH decreases two tenths while the peak of chlorine. As for the temperature it shows small variations. The conductivity presents an insignificant rise from 1286 to 1293 µS/cm.

These chlorine increases are related to the implementation of the system since it requires a stabilization time.

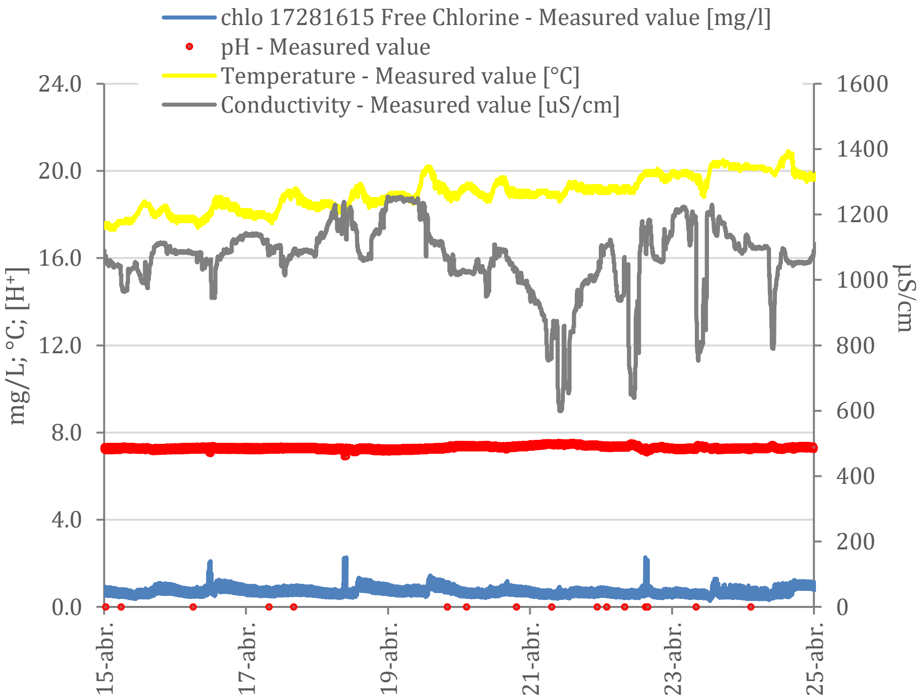
<u>April 2018</u>



***Graph A.31:** Free chlorine recorded by pipe::scan from April 15 to April 25 2018*

Graph A.31 gives information about the concentration of free chlorine for ten days. There are three points that suppers the concentrations of 1 mg/L. Moreover, there are a tendency to increase the concentration at the beginning of the day (8 a.m. – 9 a.m.) and decrease during the night.

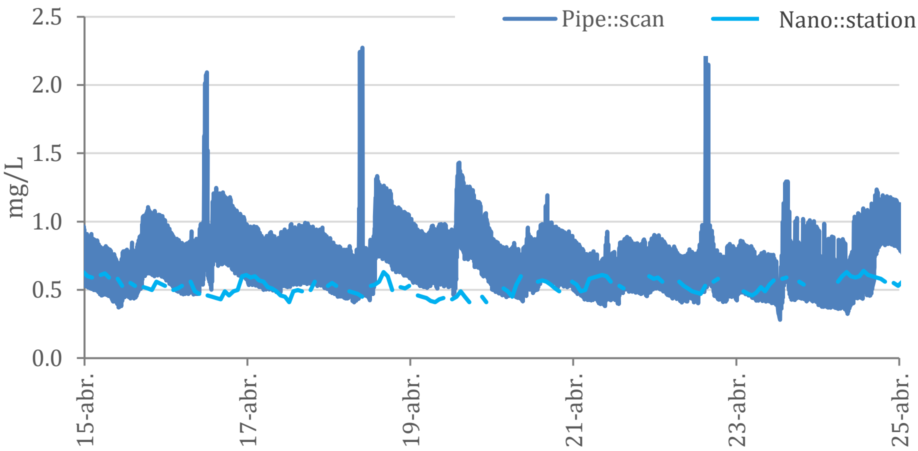
These three high points appears at 3 p.m. and they have a value greater than 1 mg/L. Then, the chlorine parameter is analysed with conductivity, pH and temperature.



Graph A.32: *Free Chlorine, pH, temperature and conductivity recorded by the pipe::scan from April 15 to April 25 2018*

It is observed in graph 32 that chlorine peaks coincide with pH drops. Temperature shows an increase just after the peak of chlorine (increase of 2 degrees). Referring to conductivity, it appears to fall at the same point as the chlorine increase.

Comparison of free chlorine registered by the pipe::scan and free chlorine registered by nano::station is shown in graph A.33.

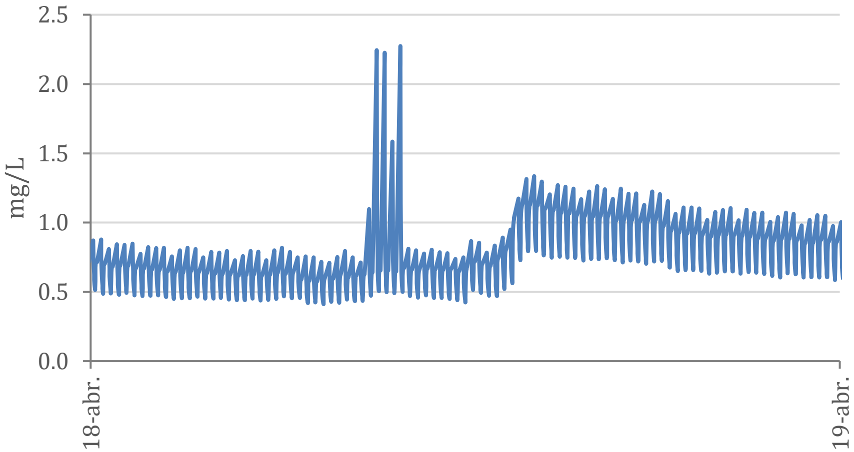


Graph A.33 *Free Chlorine registered by pipe::scan and free chlorine registered by nano::station, from April 15 to April 25 2018*

It is observed in graph A.33 how the nano::station measures lower values and these peaks are not as high as the pipe::scan marks.

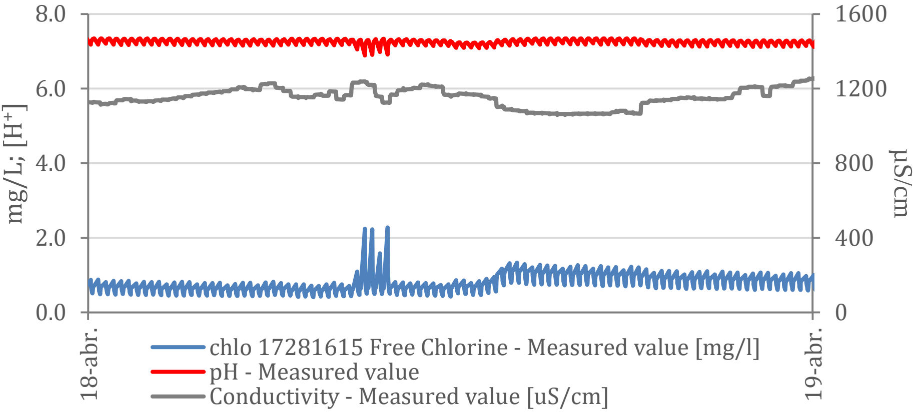
It could be an error in the reading of pipe::scan, or an alteration in the internal network.

Another similar event that is observed during the month of April is the one shown in graph A.34:



Graph A.34: *Free chlorine recorded by pipe::scan from April 18 to April 19 2018*

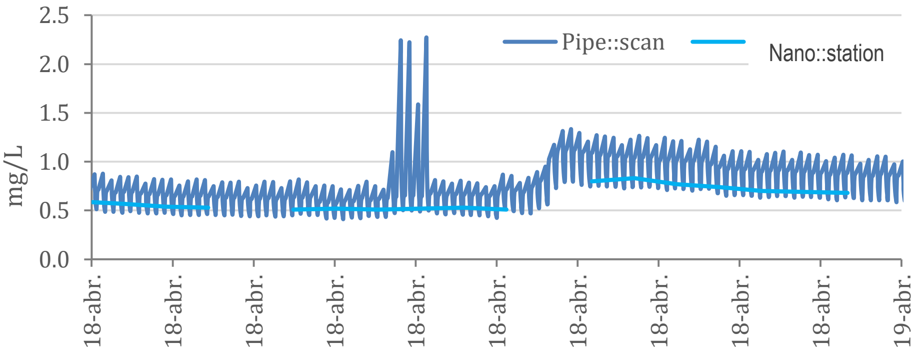
Graph A.34 show a very high chlorine peak at 9.10 a.m. where the concentration is 2.244 mg/L. This value stays for a short time. There are only 8 measures that come out, the rest of the values registered during this same time interval are inside the range.



Graph A.35: *Free Chlorine, pH and conductivity recorded by the pipe::scan from April 18 to April 19 2018*

Graph A.35 doesn't show the parameter of temperature since no change is observed (it stays constant at 18.2-18.3ºC during the whole period of time, including when the chlorine peak appears).

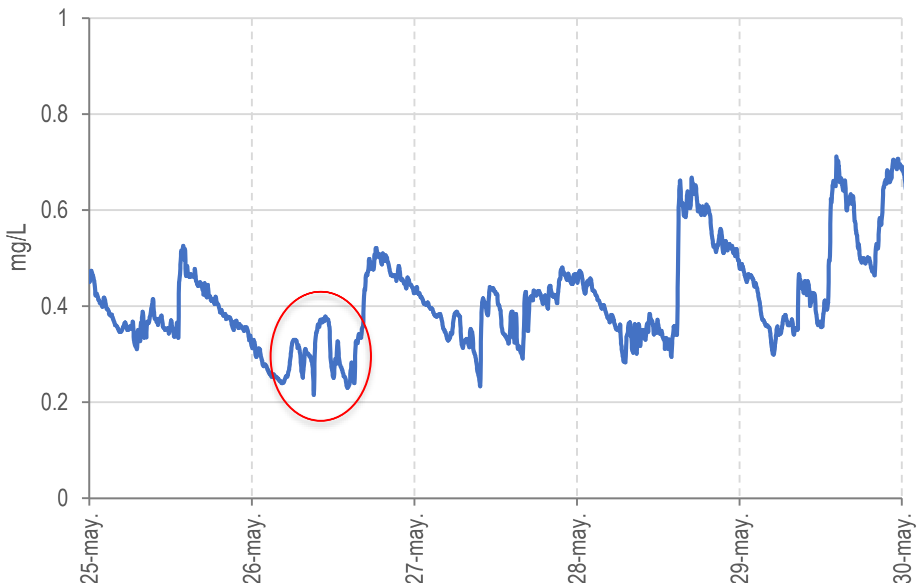
Regarding the pH, there is a drop at the same point as the rise in chlorine. The conductivity presents a small increase of concentration, but any conclusions can be drawn as the change is no significant. To confirm that it is an out-liar value compare it with the sensor placed on the network (nano::station):



Graph A.36: *Free Chlorine registered by pipe::scan and free chlorine registered by nano::station, from April 18 to April 19 2018*

It is observed how the sensor of the network does not record any alteration of the chlorine. Therefore, it is an out-liar value.

May 2018

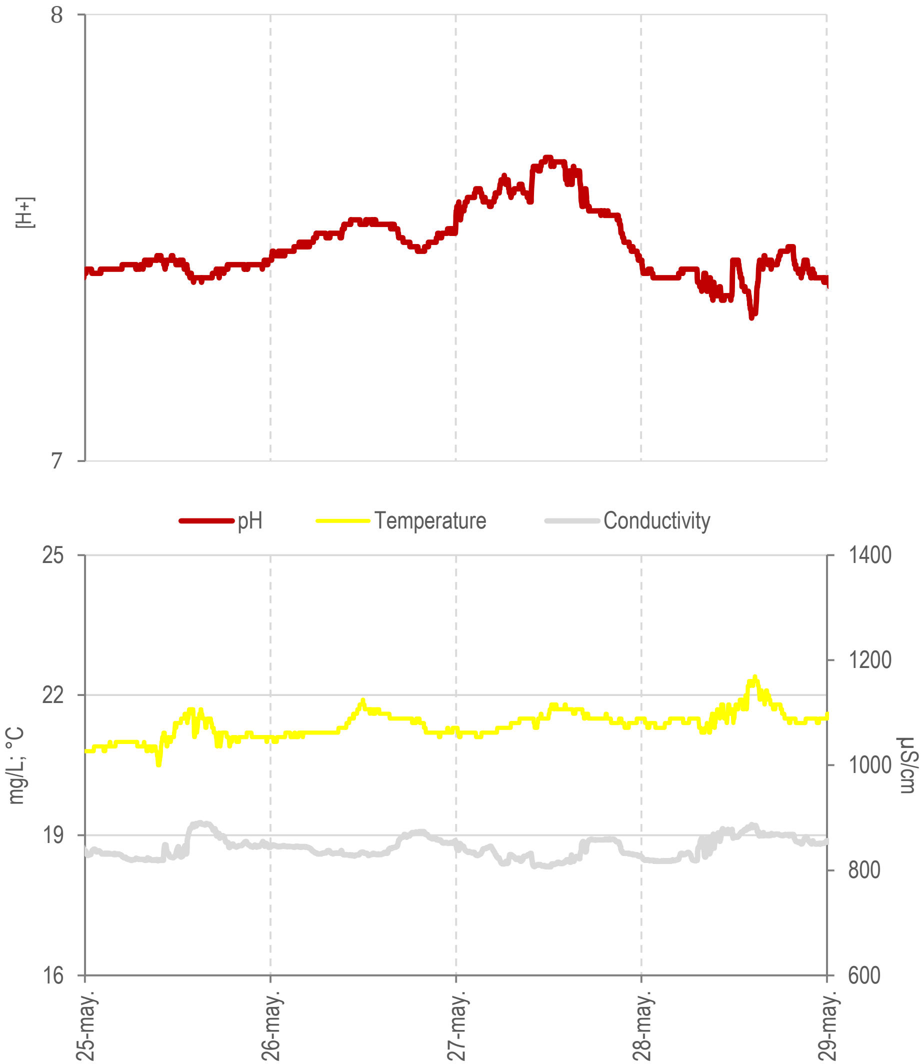


Graph A.37: *Free chlorine recorded by pipe::scan from May 25 to May 30 2018*

Graph A.37 show very low chlorine concentrations. A pattern is observed: chlorine concentration is higher at the first time of the day and as it progresses it is decreasing until it reaches minimum values at night. This is because at the first hours of the day the demand for water in the area is higher and therefore direct water arrives from the network.

As the demand decreases, the water stays in the pipes and loses chlorine, which is why the concentration of chlorine registered in low demand hours is lower. It is necessary to look for water exit of the sector to know what concentration of chlorine leaves.

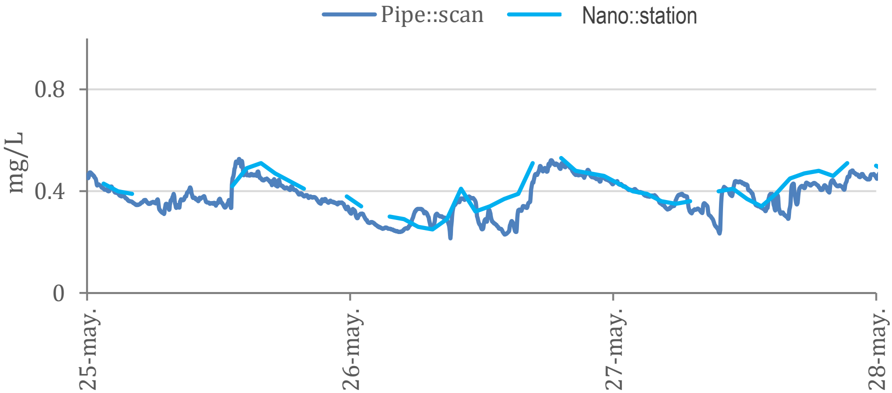
If free chlorine parameter is compared with the conductivity, the temperature and the pH, graph A.38 is obtained.



Graph A.38 *Free Chlorine, pH and conductivity recorded by the pipe::scan from May 25 to May 29 2018*

The other parameters do not show any variation.

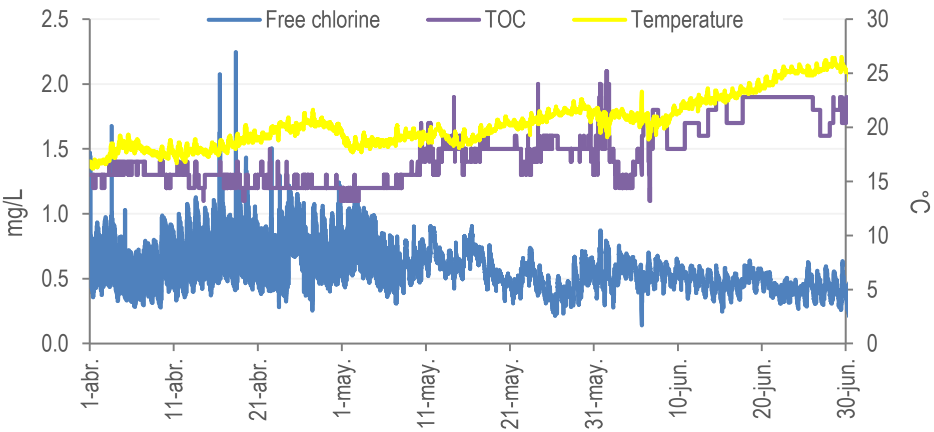
If the data registered by the pipe::scan is compared with the free chlorine data registered by nano::station graph A.39 is obtained;



***Graph A.39:** Free chlorine trend from May 25, 2018 to May 28, 2018. Parameters measured by the pipe::scan and the nano::station*

It is observed how free chlorine performance is the same in both sensors, therefore this disturbance comes from the network.

The demand for chlorine is high, so these values are recorded so low. There is a ratio of ¼ of filtered water to the total discharge. To see the chlorine behaviour during the year, it is Graph together with the TOC and temperature over a three-month period. Graph A.40 shows this comparison.



***Graph A.40:** record of free chlorine, TOC and temperature behaviour for three months: from March 25 2018 to June 30, 2018. Data recorded by pipe::scan.*

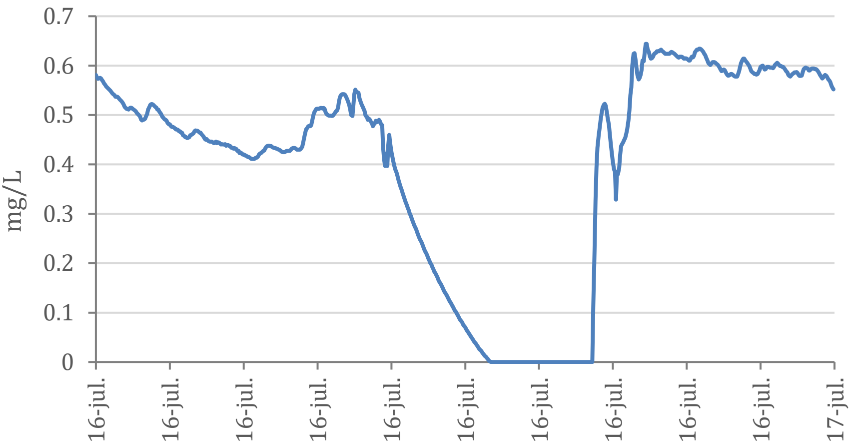
Graph A.40 shows an increase of temperature during three months along with TOC. The chlorine concentration, however, is decreasing.

Increasing water temperature promotes bacteriological activity and initiates new reactions. Therefore, TOC concentration is increase at the same time as temperature. Due to these new reactions free chlorine concentration decreases to a limit value

These low concentrations of chlorine are a phenomenon that happens every year. In late spring, when temperature starts to rise it must be considered that these reactions can occur. Therefore, the treated water must have higher chlorine concentrations, in order to be able to reach quality conditions to users.

10.1.2 System stoppage

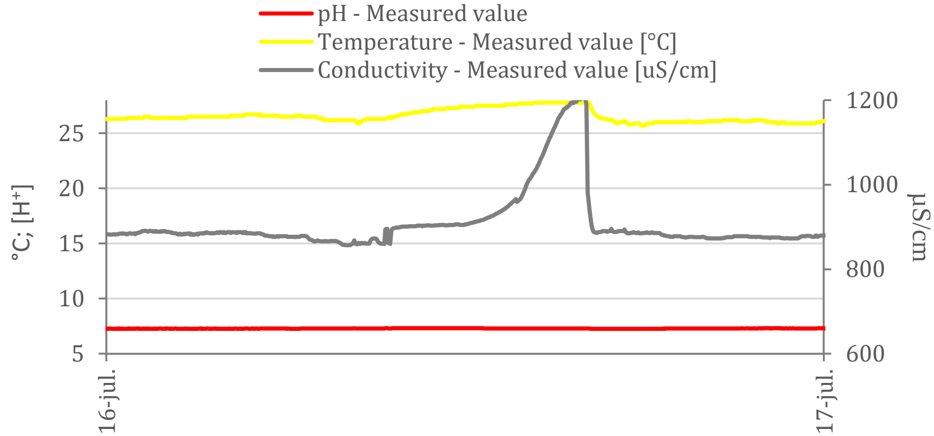
<u>July 2018</u>



Graph A.41: *Free chlorine recorded by pipe::scan from July 16 to July 17 2018*

Graph A.41 shows a decrease in chlorine concentration. This concentration drops until it reaches a null value. This decrease starts in the morning and reaches 0 mg/L at 12.50 p.m. There is an increase in concentration after 4 hours, where the chlorine is again reaching a standard value.

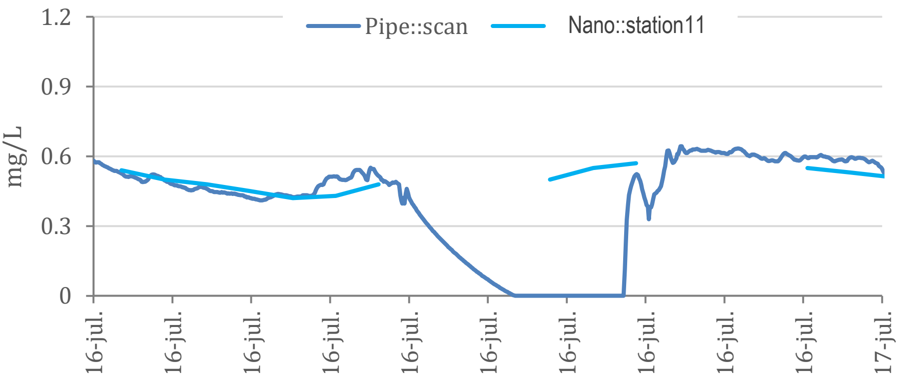
If the chlorine parameter is compared with parameters such as conductivity, flow and temperature, graph A.42 is obtained:



Graph A.42: *pH, temperature and conductivity recorded by the pipe::scan from May 25 to May 29 2018*

All parameters are affected in this time interval. The conductivity has an increase in concentration till 1200 µS/cm, the temperature increases in value (from 25ºC to 28ºC), and the pH shows a small variation. This event does not have the characteristics of a change of water since it occurs in a short time interval and within a few hours the parameters will be stabilized again.

Suppose it is a stop of the tap. To verify that it is a stop of the particular tap where the pipe::scan is located, we compare the concentration data of chlorine with the nano::station, since this sensor registers the data directly from the network.



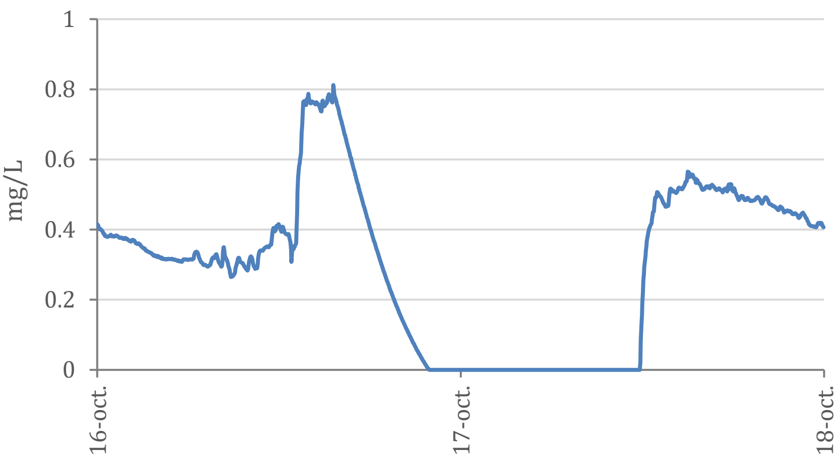
Graph A.43: *Free chlorine trend from May 25, 2018 to May 28, 2018. Parameters measured by the pipe::scan and the nano::station*

Graph A.43 shows how the nano::station has a lower registration frequency than the pipe::scan since it takes samples every 30 minutes. However, it can be observed that the concentration of chlorine does not record values close to zero and that its registered values like the pipe except for the moment of the stopover.

There is a long-time interval where nano::station is not measuring and just matches the tap stop. Therefore, clear conclusions cannot be drawn from the graph A.43.

It is confirmed that during this time interval there was a stop of the tap, that is why these timely alterations of the parameters.

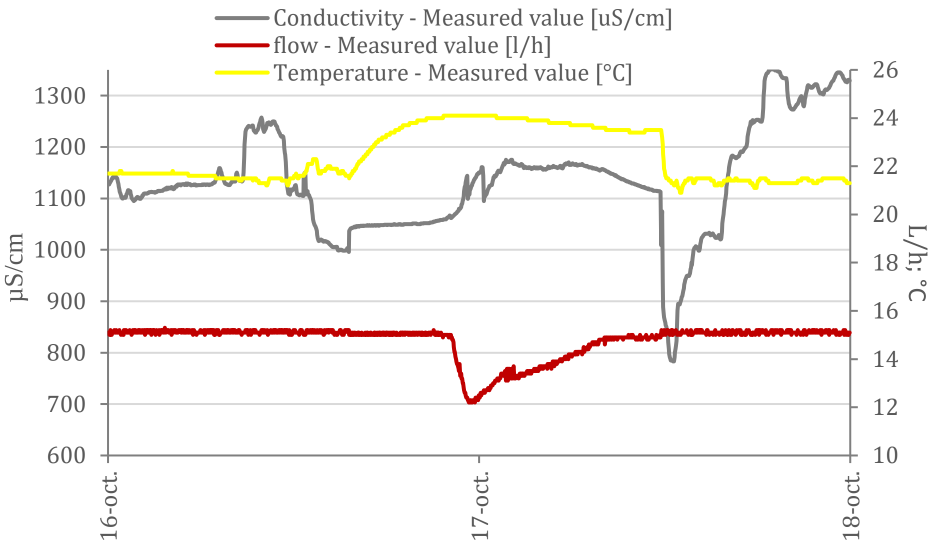
October 2018



Graph A.44: *Free chlorine recorded by pipe::scan from October 16 to October 18 2018*

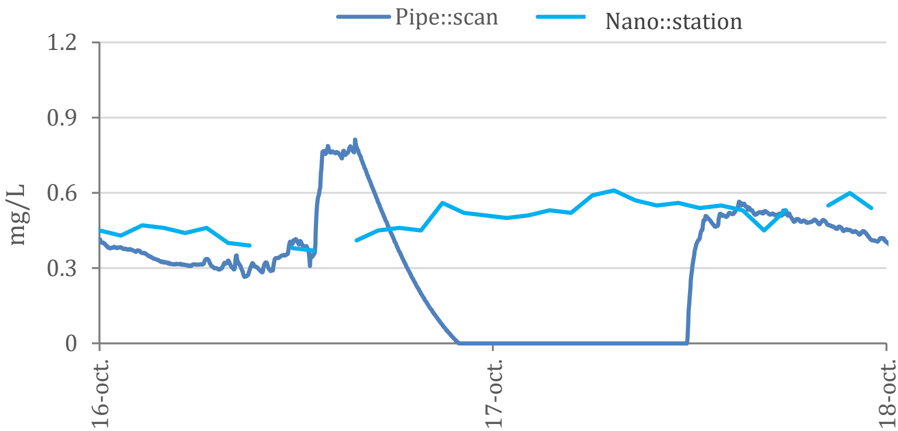
Note that during October there was a very pronounced free chlorine fall. The concentration value is zero at 9.51 p.m. and it does not retrieve it until the next day at 11.52 a.m. The performance is like the event that occurred during July.

If free chlorine parameter is compared with the conductivity, the flow and the temperature it can be observed something very strange. During the period of time where there is no chlorine concentration, there is still a value of water flow, which has no explanation because this would mean that distilled water is coming out to the network directly and that is not possible. The conductivity has a decrease at the same time as free chlorine increases.



Graph A.45:*Flow, temperature and conductivity recorded by the pipe::scan from May 25 to May 29 2018*

To verify that it is a stop of the particular tap where the pipe::scan is located, we compare the concentration data of chlorine with the sensor X since it is located in the network.

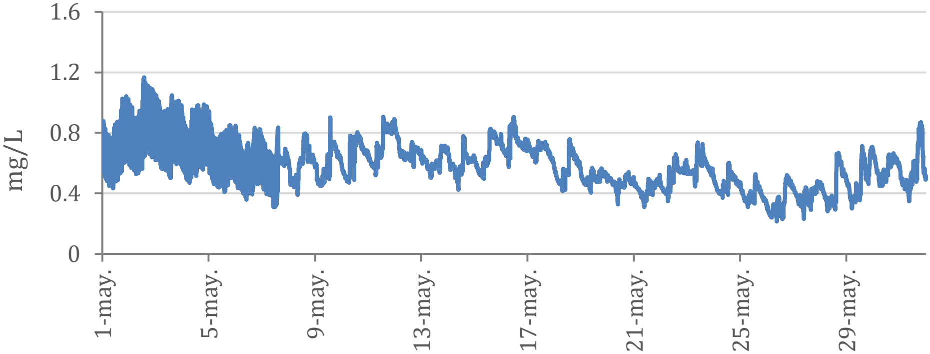


Graph A.46: *Free chlorine trend from May 25, 2018 to May 28, 2018. Parameters measured by the pipe::scan and the nano::station*

It can be observed how nano::station records different chlorine concentration data at all times. It can compared as in the interval of time that the concentration marks zero registered by pipe::scan sensor, the nano::station registers data of 0.5 mg/L. Therefore, the problem is due to an internal incident and not from the network. (Confirmed, timely internal incidence).

10.1.3 Demand for water

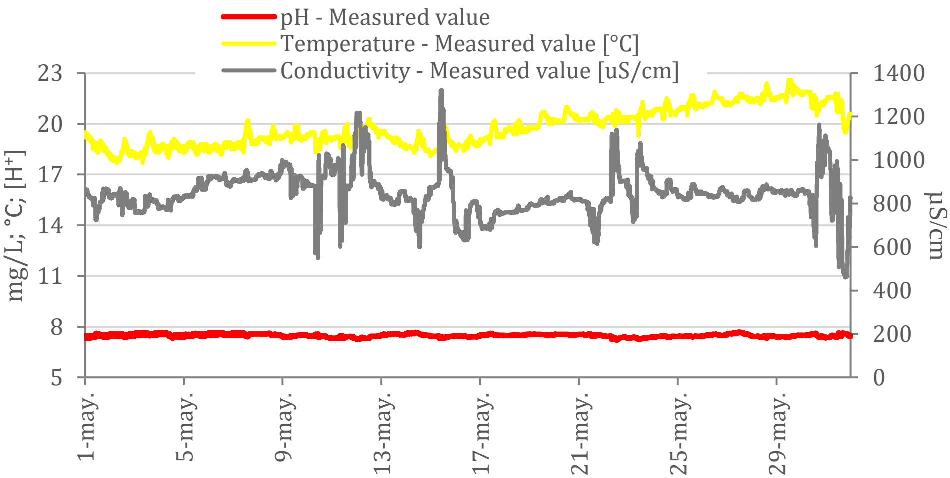
May 2018



Graph A.47: *Free chlorine recorded by pipe::scan from May 1 to June 1 2018*

Graph A.47 shows how during the whole month of May it is observed at the beginning of the month, the demand for chlorine is considerably higher than at the end of the month.

It can be assumed that this difference in demand for chlorine is due to the demand for water in the area. To verify it we first cross it with pH, conductivity and temperature.

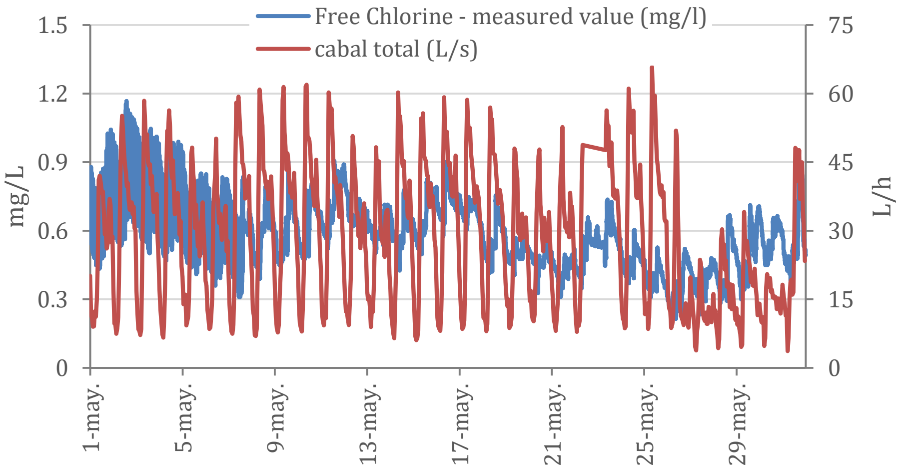


Graph A.48: *flow, temperature and conductivity recorded by the pipe::scan from May 25 to May 29 2018*

The pH stays constant throughout the month. The temperature shows an increase, at the beginning of the month, temperature registered values of 20-18ºC and is increasing to 22-24ºC at the end.

Conductivity shows changes due to changes water. At the beginning of the month it has values around 800 µS/cm, typical of Ter's water with a mixture of desalination plant. There are variations ranging from 600 µS/cm up to 1200 µS/cm on day eleventh and twelfth.

To see the relationship between the increase in chlorine and the water demand in the sector. Free chlorine concentration is crossed with water flow in the sector:

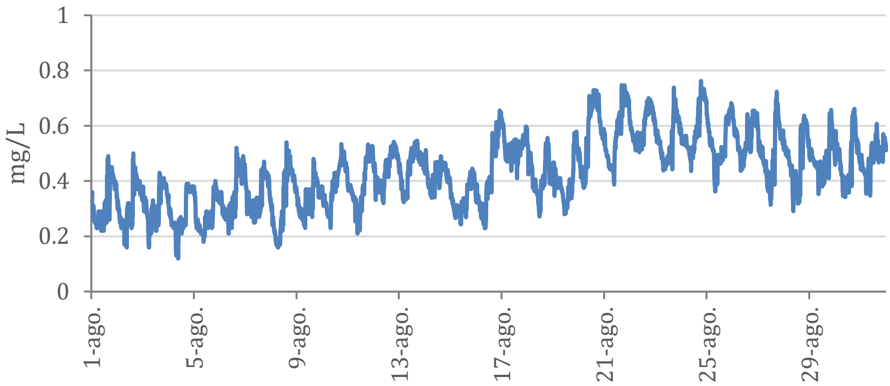


Graph A.49: *Free Chlorine registered by pipe::scan crossed with total flow registered in check point of Àlaba and Llull. Data from may 1 to June 1 2018.*

Graph A.49 show the demand for water in the area and the concentration of free chlorine. It is observed that at the end of the month the concentration of chlorine is lower since the total discharge of zone is lower.

The chlorine peaks coincide with the flow peaks, since when there is more demand for water, the concentration of chlorine is high. This happens because the water comes out directly from the plant and does not remain closed to the pipes (when there is low demand for water, this happens, and chlorine is lost).

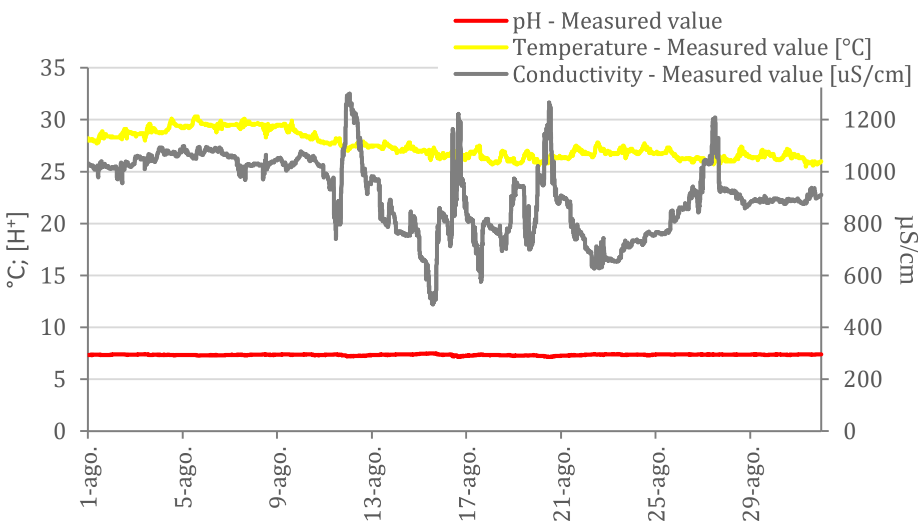
August 2018



Graph A.50: *Free chlorine recorded by pipe::scan from August 1 to September 1 2018*

During the month of August, it is observed how the concentration of chlorine has a higher value at the end of the month. As of the 16th there is an increase in concentration that lasts until the end of the month. The characteristic peaks of the first hour of the day are observed when the demand for water is higher.

Free chlorine is comparted with the conductivity, pH and temperature and graph A.51 is obtained:

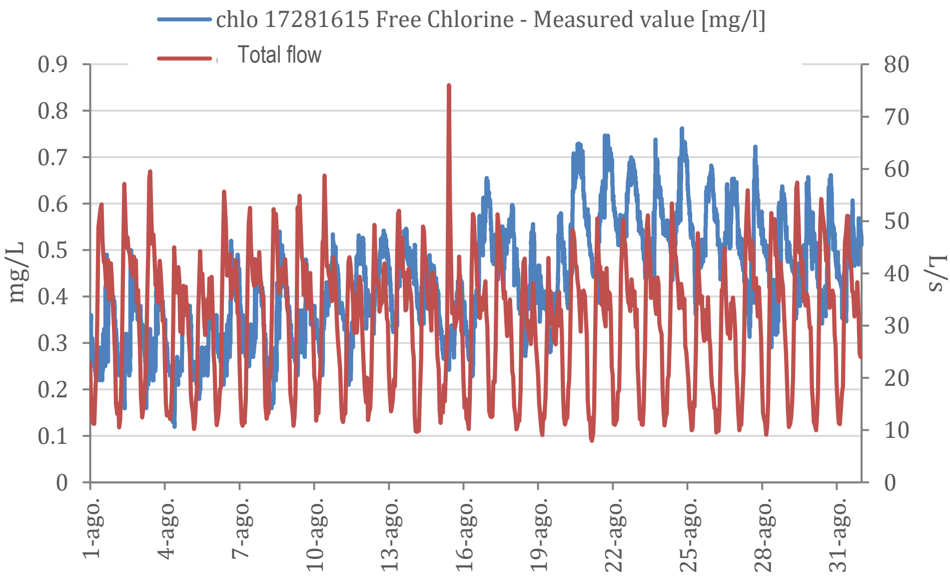


Graph A.51 *pH, temperature and conductivity recorded by the pipe::scan from August 1 to September 1 2018*

The pH does not show any variation throughout the month. The temperature decreases about five degrees from day 15.

At the beginning of the month conductivity shows a stable value and from day 11 it presents variations ranging from minimum values of 500 µS/cm to maximum values of 1300 µS/cm. These oscillations are maintained until the end of the month.

To see the relationship between the increase in chlorine and the water demand in the sector, free chlorine parameter is crossed with water flow in the sector:

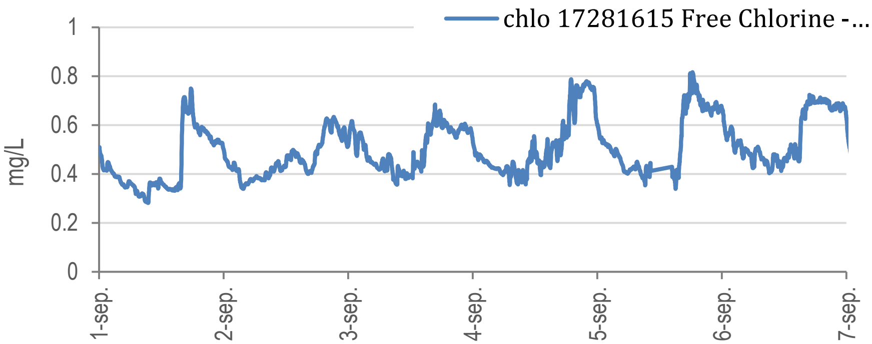


Graph A.52: *Free Chlorine registered by pipe::scan crossed with total flow registered in check point of Àlaba and Llull. Data from August 1 to September 1 2018*

Graph A.52 shows the demand for water in the area and the concentration of chlorine. There is a demand for water of 70 L/s on day 15, well above the rest of the month. It can be seen how chlorine peaks coincide with peaks of maximum demand.

However, in this case we cannot relate the increase in chlorine concentration with an increase in demand as it stays constant throughout the month.

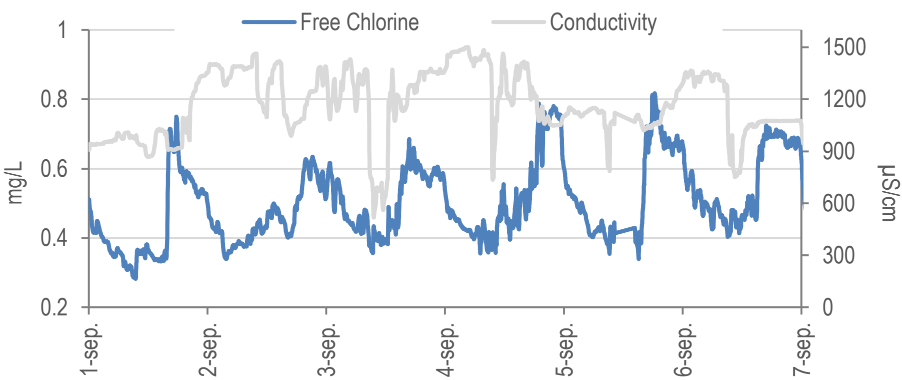
September 2018



Graph A.53. *This graph shows the behaviour of free chlorine from September 1 to September 7, 2018. Data recorded by the pipe::scan.*

These oscillations in free chlorine concentrations have been observed in different months. Graphic A.53 shows the month of September because an increase chlorine concentration is very pronounced in a short time.

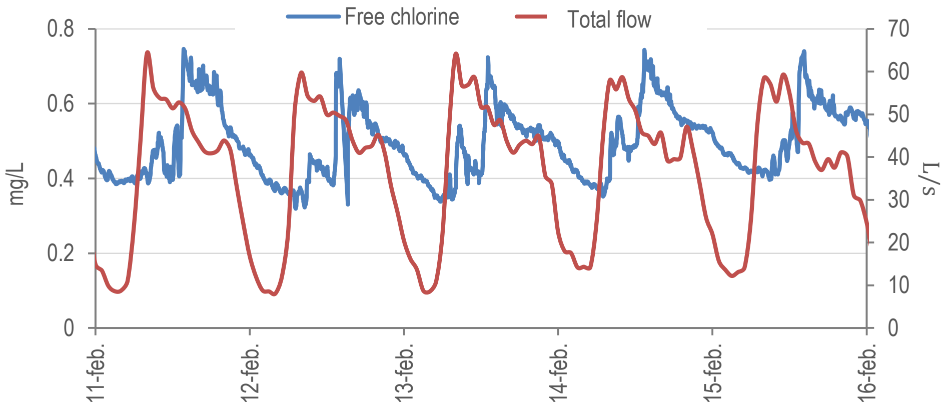
The chlorine concentrations show oscillations that mark values from 0.3 mg/L to 0.8 mg/L. These peaks all coincide at around 7 p.m. every day. The free chlorine concentration is crossed with conductivity temperature and pH analysed by the same sensor inside the building to see if there is a possible change of water. Graph A.54 is obtained



Graph A.54: *Free chlorine and conductivity behaviour from September 1, 2018 to September 7, 2018. Data recorded by the pipe::scan.*

Graph A.54 shows the relationship between free chlorine concentration and conductivity. There is no clear relationship between these two parameters, both follows a different trend.

The concentration of free chlorine is crossed with the flow demand. Water demand is measured at the control points of Llull street and Àlaba street

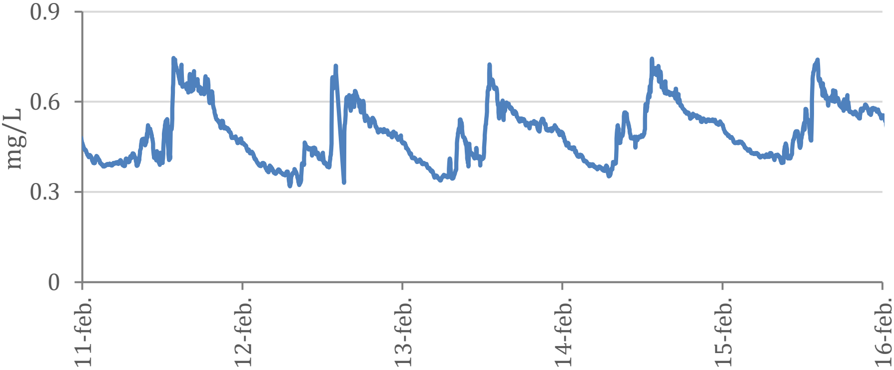


Graph A.55: *Water entry from the registered sector at the checkpoints in Llull and Àlaba from September 1 to September 9, 2018. Free chlorine concentration recorded by the pipe::scan over the same time interval.*

Graph A.55 shows the relationship between free chlorine concentration and the water demand in Llacuna sector. Both parameters show the same behaviour. However, chlorine peaks appear hours later than the flow peaks. This occurs because the sensor is placed at a certain distance from the control point and therefore the hours of maximum demand do not coincide in the graph. For this reason, an hourly shift appears in the graph.

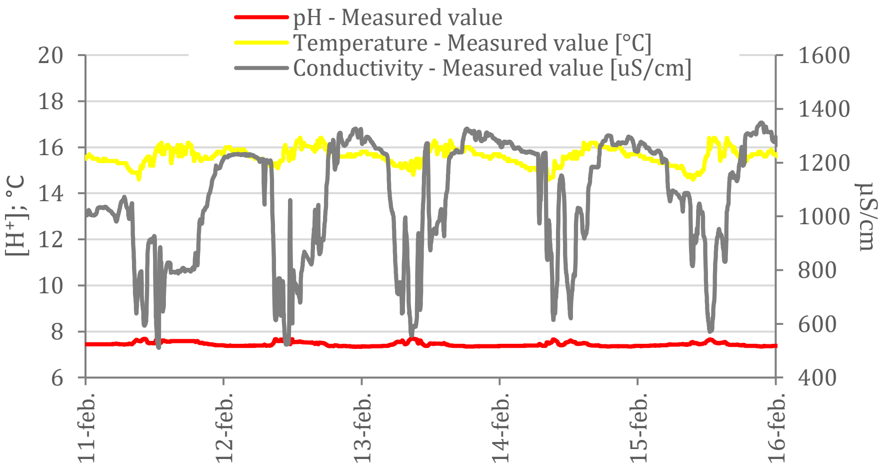
There are hours of the day where the demand for the sector is higher. In the morning there is more water expenditure than at night, as there are more people using it. When the water demand is high, the two control points are opened, and the concentration of chlorine is high. The residence time in a distribution network influences. The longer the water passes inside the pipe, the more chlorine is consumed since the biological activity increases. Consequently, the chlorine concentration decreases.

February 2019



Graph A.56: *Free chlorine recorded by pipe::scan from February 11 to February 16 2019*

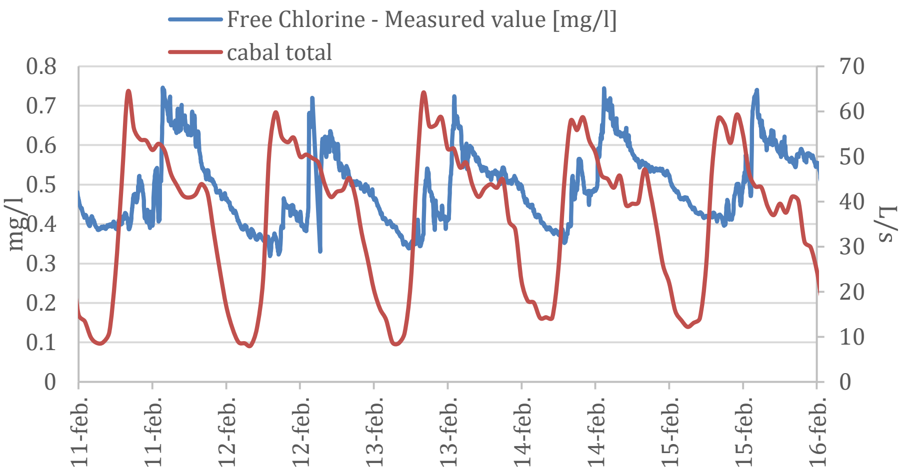
It is observed that the concentration of chlorine changes a lot depending on the time. The highest concentration points are at values of 0.7 mg/L and occur at midday (about 2:00 p.m.). The lowest chlorine values are found overnight. This is due to the demand for water that depends on the time of day. In a lot of activity (in the morning, lunch time, etc.) the demand is higher and therefore reaches direct water network with a high chlorine concentration. In low demand hours, as the water remains closed inside the pipe, it loses chlorine and therefore the concentrations recorded are lower.



Graph A.57: *pH, temperature and conductivity recorded by the pipe::scan from February 11 to February 16 2018*

Graph A.57 shows how the conductivity oscillates between values of 1200 and values of 600 µS/cm this is due to a change of water. When its records values close to 1200 µS/cm, the water is from the Ter. When registering lower values, close to 600 µS/cm, water is a mixture of Llobregat with desalination. The chlorine peaks coincide with the conductivity peaks, this is because there is a lot of water demand in the area. In this case the pH does not show any variation and the temperature oscillates between 15-16 ºC.

Free chlorine is compared with the total flow on the sector:



***Graph A.58**: Free Chlorine registered by pipe::scan crossed with total flow registered in check point of Àlaba and Llull. Data from August 1 to September 1 2018*

It is observed in the graphic A.58 how the concentration of chlorine and the water flow in the area have the same behaviour. The difference in time is because the sensors are placed at different distances. When the demand for water is high, the two control points are open, and the concentration of chlorine is high.

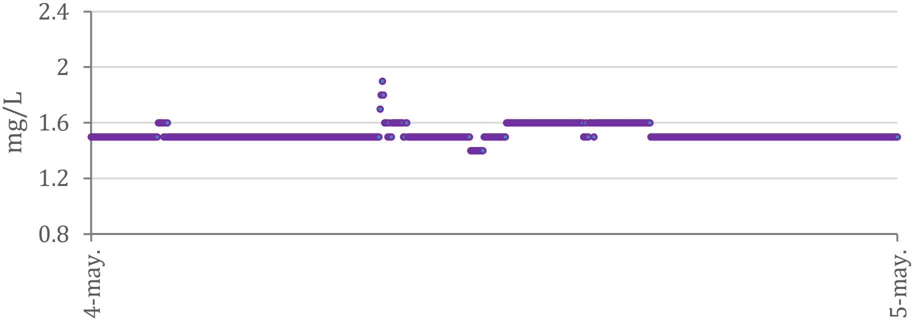
When the concentration is lowered, only one control point is opened, and the concentration is lowered.

10.2 TOTAL ORGANIC CARBON (TOC)

Of the annual study of TOC behaviour, different events have been analysed.

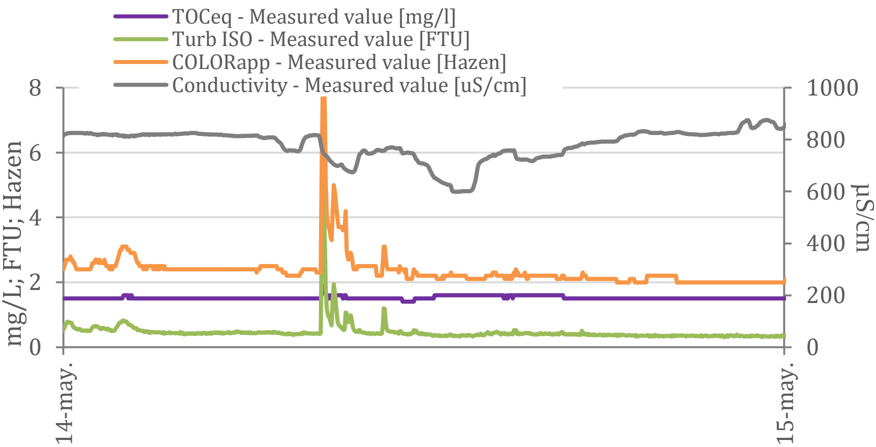
10.2.1 Change of water

<u>May 2018</u>



Graph A.59: *TOC recorded by pipe::scan from May 141 to May 15 2018*

It can be observed how in graph A.59 at 8:40 a.m., on day 14 there is a rise in concentration and reach a value of 1,9 mg/L. Half a second after measuring a concentration of 1,8 mg/L, then it stays two minutes at 1,7 and returns to the value of 1,5 mg/l. TOC parameter is compared with conductivity turbidity and colour:

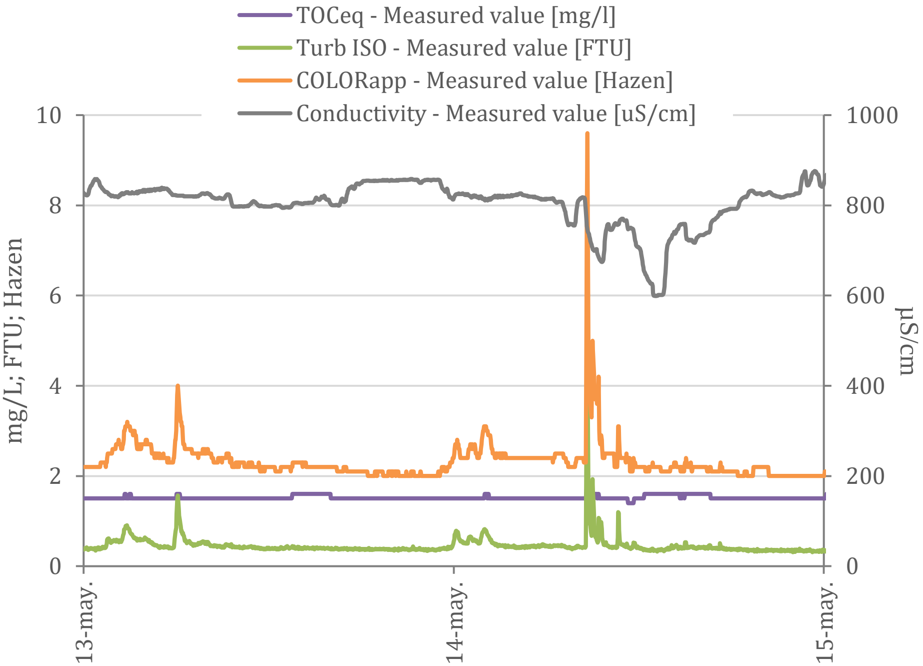


Graph A.60: *TOC, conductivity, turbidity and colour parameters registered by pipe::scan from May 14 to May 15 2018.*

Graph A.60 show how the colour and turbidity have the same behaviour. In the same place where increase in TOC appears, a very sharp peak of turbidity and colour is observed. The conductivity decreases just after this point and retrieves the value it had initially after a few hours.

It can be observed that there is a relationship between the rise in TOC and the change in conductivity. This is due to a change of water at that time. The conductivity prior to the TOC peak registers values of 800 µS/cm, values that normally recorded in Llobregat's water. Just as the same time as the TOC, turbidity and colour peak occurs, the conductivity decreases to 600 µS/cm. Ter's water usually has conductivity values of 400 µS/cm, therefore this decrease in the value of the conductivity is due to a water entrance of the Ter.

If the time zone is extended to 72 hours (to observe the performance of conductivity):

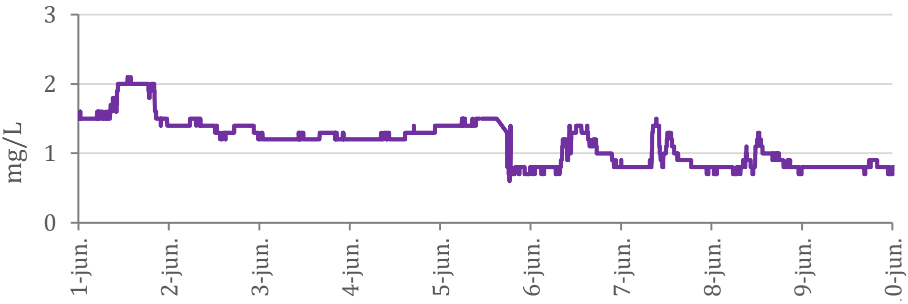


Graph A.61: *TOC, conductivity, turbidity and colour parameters registered by pipe::scan from May 13 to May 15 2018*

It is observed with the 72h band that the conductivity stays constant during a period of time of a day (there is no change of water). Just at the moment where the TOC peak occurs (May 14 at 8 a.m.), there is a decrease in conductivity (due to the water join of the Ter's river).

10.2.2 System stoppage

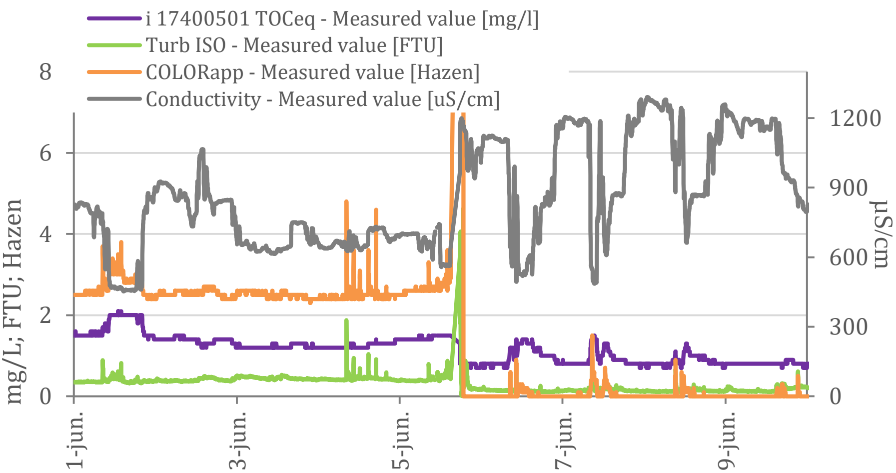
June 2018



Graph A.62: *TOC recorded by pipe::scan from June 1 to June 1 2018*

During the first week of June, oscillations of the concentration of TOC are observed. There is a peak that reaches up to 2.1 mg/L during the morning of day 1. After this peak the value varies between 1.2 and 1.0 mg/L, until day 5 reaches up to 1.5 mg/L during a long interval of time (7 hours). At 18 in the afternoon, the concentration falls into a bite (values of 0.8 mg/l). The TOC stabilizes a few hours in this value and returns a peak to values of 1.4 and 1.5 mg/l.

Toc parameter is compared with the parameters of conductivity, turbidity and colour to see what relation there is:



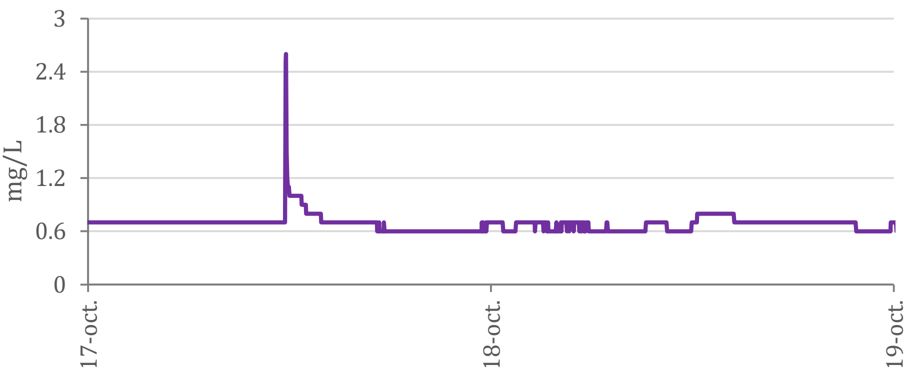
Graph A.63: *TOC, conductivity, turbidity and colour parameters registered by pipe::scan from June 1 to June 1 2018*

On June 5th at 5:49 p.m., a very pronounced colour peak is observed (up to a maximum of 56.6 Hazen). This rise in colour is also observed in the turbidity variable where a peak appears at the same time of 46.23 FTU (very high value).

Graph 63 is interrupted for a few minutes since there are no data recorded during this period. After the stop the conductivity makes a very large jump where it passes from a low value of 632 to a value of 1112 µS/cm (and increasing).

This stop lasts two hours. When the equipment is started again, it needs a stabilization time, so there are those peaks that are so high. After this point, the change in conductivity is directly related to a change in water. Before the stop, the conductivity registers a concentration of 600 µS/cm. These values are typical to Ter's water with a desalination mix. When the conductivity marks a value of 1200 µS/cm, it means that there has been a water entrance from the Llobregat's river, since this water usually registers these values. From this point the conductivity is varying since it depends on the demand of the zone: if the demand is high, Ter's water joins. That is why these conductivity peaks appear.

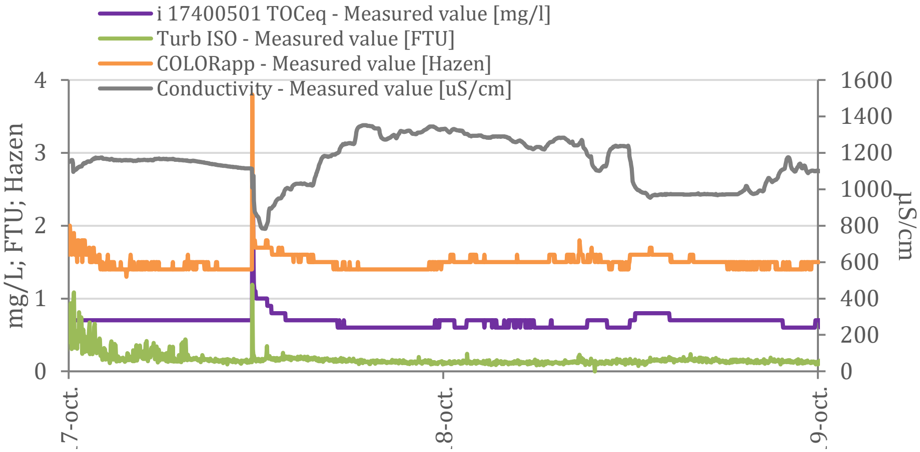
<u>October 2018</u>



Graph A.64: *TOC recorded by pipe::scan from June 1 to June 1 2018*

Graph A.64 shows a peak that has a value of 2.6 mg/L registered on day 17 at 11:48 a.m. The concentration oscillates from 0 to 2.6 mg/L in 2 minutes. After this peak it registers decrease values for 10 minutes and then stabilizes to 0.5 mg/L (with small variations).

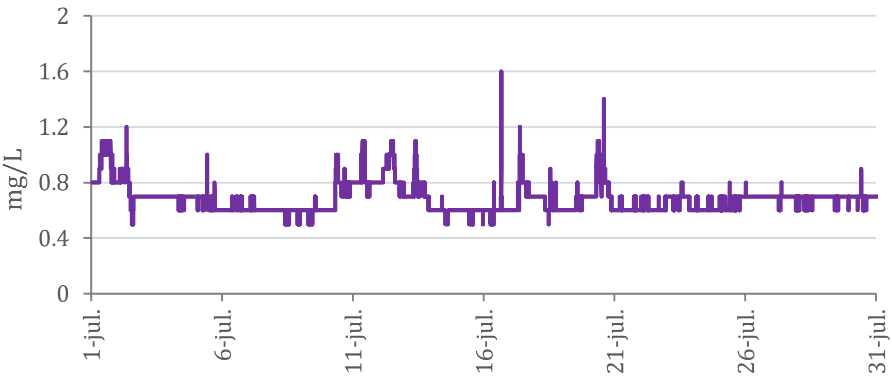
TOC is compared in this same time interval with turbidity, colour and to see what behaviour they have.



Graph A.65: *TOC, conductivity, turbidity and colour parameters registered by pipe::scan from June 1 to June 1 2018*

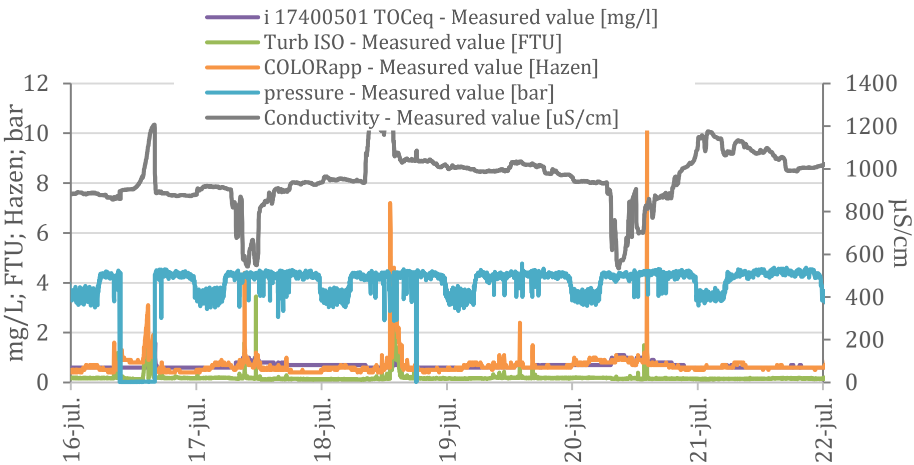
With the comparison of the other parameters it is observed that on day 17 at 11:48 a.m. the colour and turbidity have a rise. The colour registers a value of 3.8 Hazen and the turbidity registers a value of 1.18 FTU. In this case, it can be observed how the conductivity presents a variation of the concentration as there is a drop in this same point. There is a value of 1070 µS/cm and decrease to a value of 847 µS/cm (and it continues to fall). This fall in values is the consequence of a system shutdown. When the system is started again, it needs a stabilization time, so the parameters are altered.

July 2018



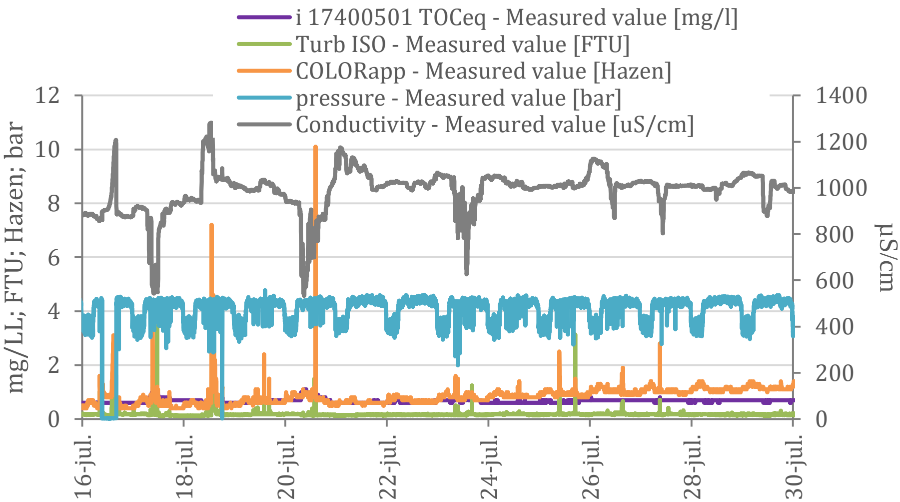
Graph A.66: *TOC parameter registered by the pipe::scan from July 1 to July 31 2018*

During the month of July some peaks that appear at 12 p.m., are observed. The highest registered value is 1.6 mg/L but it is punctual (it could be considered as an out-liar). We compare these data with the conductivity, turbidity and colour:



Graph A.67:*TOC, Turbidity colour and pressure registered by the pipe::scan from July 16 to July 22, 2018.*

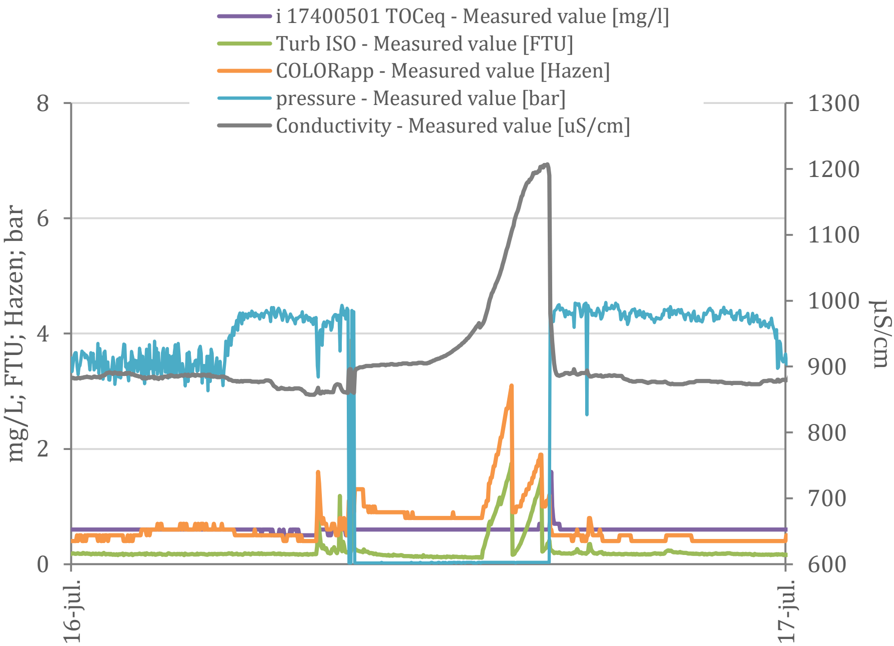
The pressure drops have to do with the demand for water in the area. They do not have to do with the specific pressure data that appear.



Graph A.68: *TOC, Turbidity colour and pressure registered by the pipe::scan from July 16 to July 30, 2018.*

It is observed that each time a TOC peak occurs, a turbidity peak and a colour peak also occur. It can be observed how the behaviour of conductivity respect to TOC show no pattern since at each peak the conductivity responds in a different way.

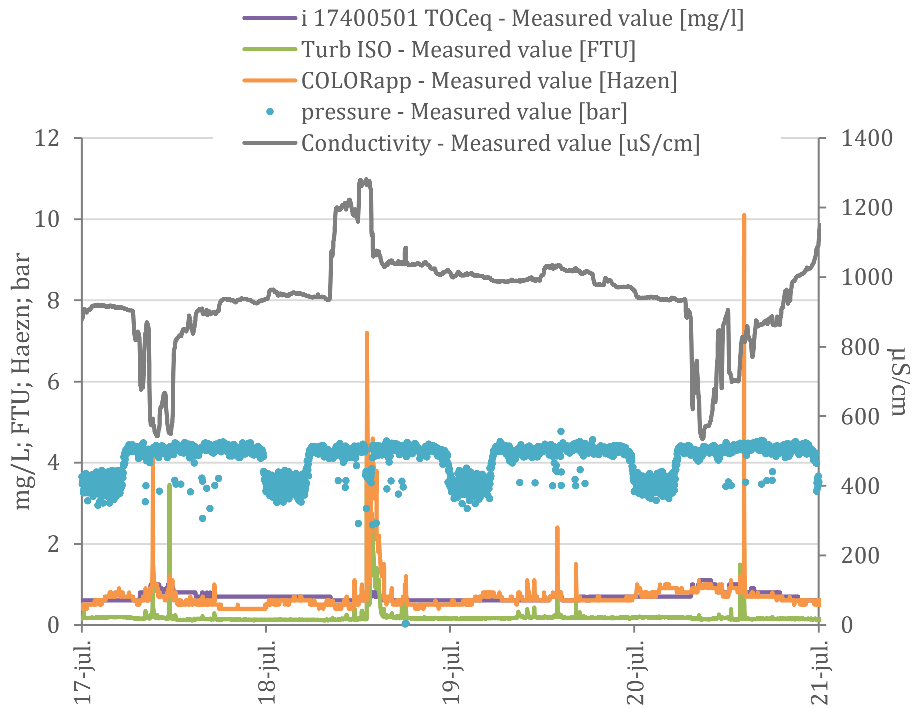
In this case it cannot always associate the TOC peaks with a change of water. In the first TOC peak, a very significant increase in the conductivity that lasts a short time is observed. During a period of seven hours, there are no values of pressure. In this range the peaks of TOC, turbidity, colour and conductivity occur. These peaks are due to a system stop. (That is why there is pressure data. Graph A.69 shows the sensor stoppage.



Graph A.69: *TOC, Turbidity colour and pressure registered by the pipe::scan from July 16 to July 17, 2018*

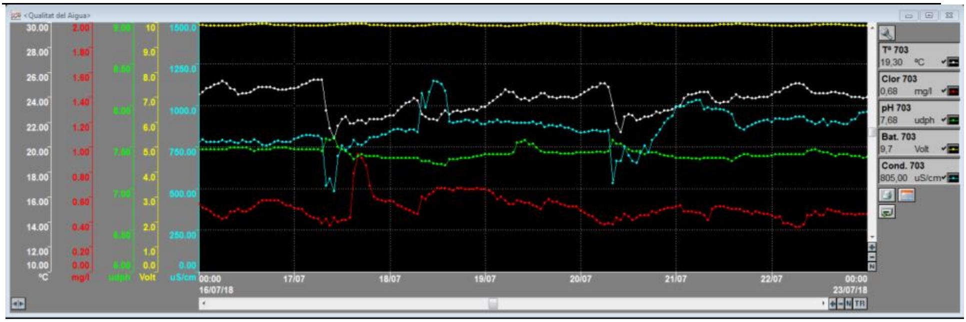
10.2.3 Change of water

The second TOC peak that appears is related to a decrease from 1000 µS/cm up to 600 µS/cm of conductivity, could be related to a change of water (from Llobregat to Ter), although the water entrance from Ter lasts very little. On the third TOC peak, conductivity rises of up to 1200 µS/cm is observed. This could be related to a purely Llobregat water source (well water entrance), without a mixture of desalination plant or Ter's water. The last peak of TOC that is observed appears just after a quite significant decrease in conductivity. It returns to vary from 1000 to 600 µS/cm, but in this case the increase in concentration of TOC does not appear at the same time.



Graph A.70: *TOC, Turbidity colour and pressure registered by the pipe::scan from July 17 to July 21, 2018*

To verify that when a sudden change occurs in the conductivity parameters are affected, we compare it with another sensor located on the network.



Graph A.71: *free chlorine, pH, conductivity and temperature registered by nano::station*

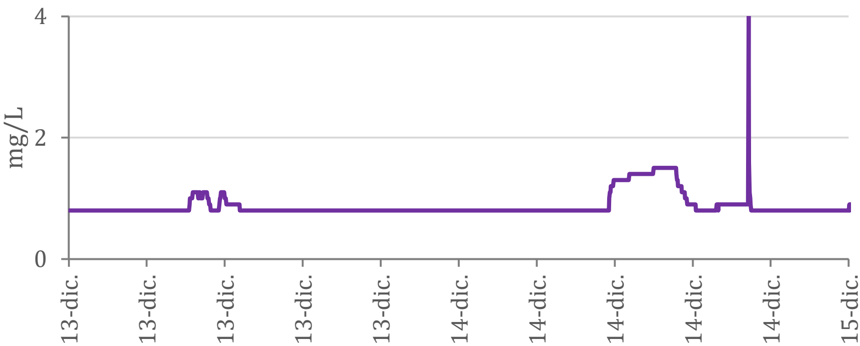
Graph A.71 shows the parameters of chlorine, pH, conductivity and temperature represented. This sensor does not measure TOC but it can be observed that in the conductivity drop of day 17 the other parameters are also affected: there is a rise in chlorine and pH and a decrease in temperature. There is also a rise in conductivity on day 18 that cause an increase in the concentration of chlorine and a decrease in temperature and pH. The conductivity drops of day 21 also causes an alteration of the other parameters.

When there is a sudden change of water that affects conductivity, the other parameters are affected and need a stabilization time, therefore they registered values outside the range.

December 2018

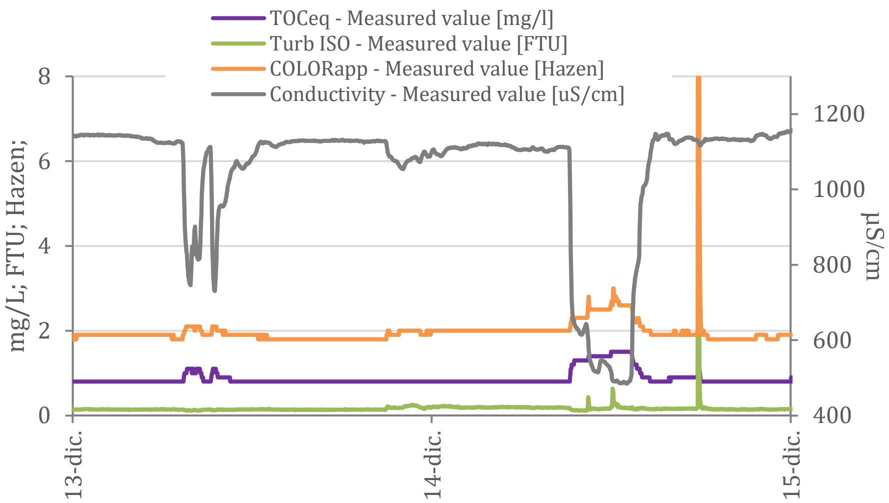
During the month of December, a peak of TOC is observed. It registers a very high value of 4 mg/l.

The graph A.72 shows this punctual event that occurred on December 14.



Graph A.72: *TOC parameter registered by the pipe::scan from December 13 to December 15 2018*

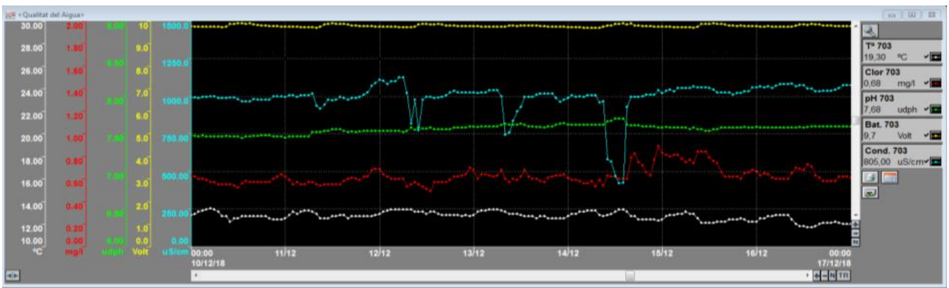
If the TOC parameter is compared with colour, turbidity and conductivity, graph A.73 is obtained:



Graph A.73: *TOC, Turbidity colour and pressure registered by the pipe::scan from December 13 to December 15, 2018*

It is observed that before the TOC peak, there is a decrease in the conductivity of 1100 up to 500 µS/cm. This is due to a change of water. In 1100 µS/cm there is Llobregat water, and there is a water entrance from the Ter. A few hours later, the TOC peak occurs.

They are very specific values and could be classified as out-liar. To check if they are out-of-range values, compare it with the nano::station placed on the network:

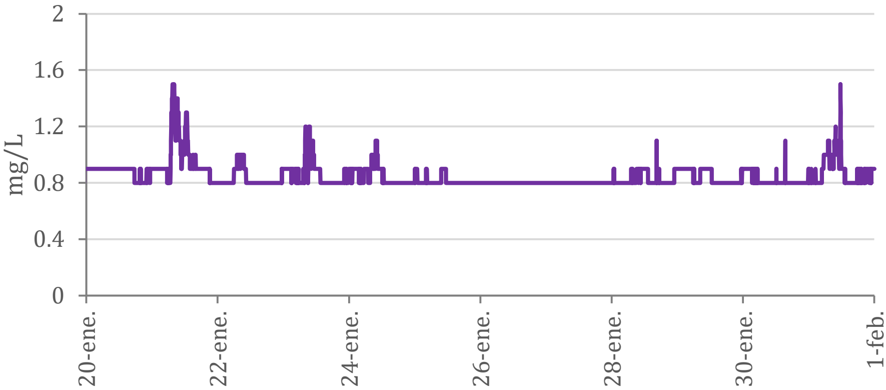


Graph A.74: *free chlorine, pH, conductivity and temperature registered by nano::station*

It is observed that the decrease in conductivity on day 14 causes an increase in the concentration of chlorine, and an increase in pH.

In this case also, it is observed how a sudden change in conductivity alters the sensor.

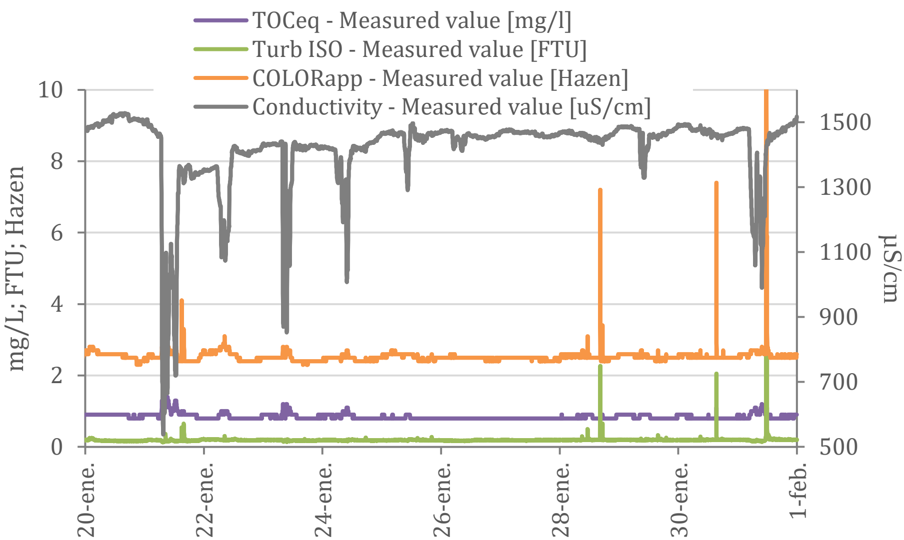
January 2019



Graph A.75: *TOC parameter registered by the pipe::scan from January 20 to February 1 2019*

During the month of January, two very sharp peaks are observed. The first one is registered on day 21 and reaches a value of 1.5 mg/L. The second peak is recorded on day 31 and reaches a value of 1-5 mg/L.

If the TOC parameter is compared with colour, turbidity and conductivity, graph A.76 is obtained:



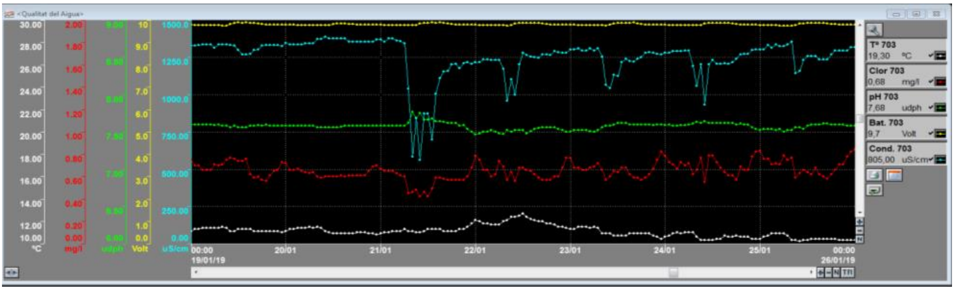
Graph A.76: *TOC, Turbidity colour and conductivity registered by the pipe::scan from January 20 to February 1, 2019*

The peak that occurs on the 21st, also coincides with a turbidity and colour peak. Conductivity at the same time, has a descent from 1500 µS/cm to 500 µS/cm, this alteration in the conductivity parameter could be the cause of the turbidity, colour and TOC peaks.

There are some colour and turbidity peaks on day 28 and day 30. There are not related to a change in conductivity. There are outliers.

The last peak occurs on day 31. There is also an increase in turbidity and colour. In addition, there is also a decrease in conductivity hours before. It passes from values of 1500 µS/cm to values of 1000 µS/cm. The peaks may be consequence of the decrease in conductivity.

Graph A.77 shows that it happens to nano::station when it records these conductivity drops:

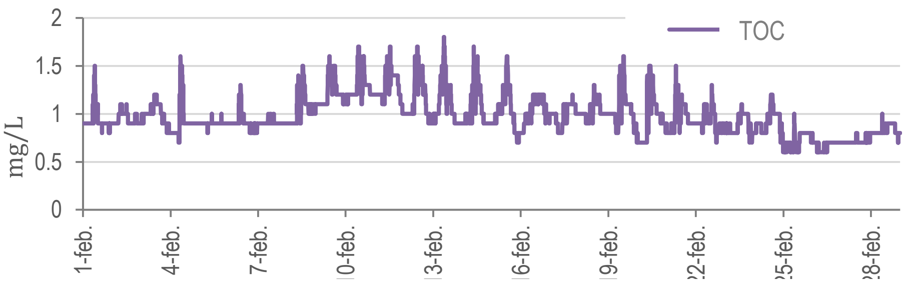


Graph A.77: *free chlorine, pH, conductivity and temperature registered by nano::station*

On day 21 there is a decrease in conductivity from 1300 µS/cm to 600 µS/cm approx. It is observed how pH and chlorine are affected by this event. During days 22, 23 and 24 there are also small decreases in conductivity but no direct relationship with the other parameters.

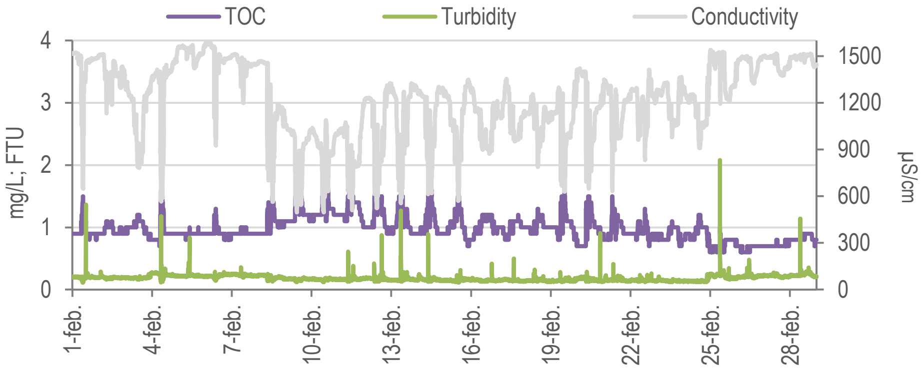
February 2019

Throughout the month of February, very sharp peaks of TOC are observed. It could be due to a constant change of water.



Graph A.78: *TOC parameter registered by the pipe::scan from February 1 to February 28 2019*

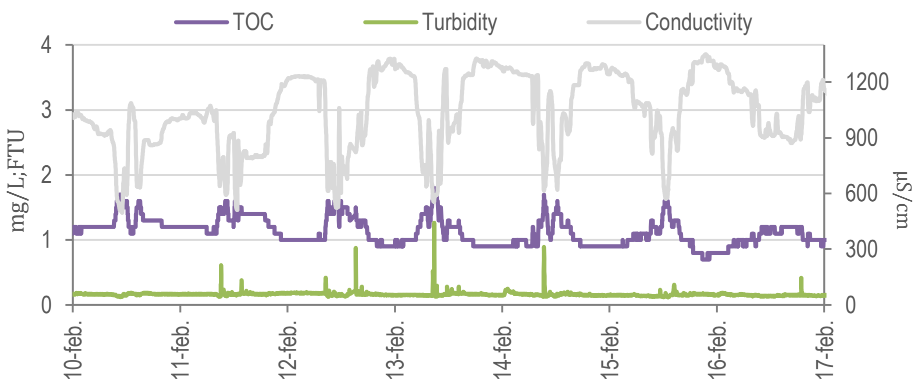
To verify this, we cross the data of TOC with turbidity, the conductivity and the colour. The following graph is obtained:



Graph A.79: *TOC, Turbidity and conductivity registered by pipe::scan from February 1 to February 28, 2019.*

Graph A.79 shows three parameters that show significant variations. The conductivity shows strong oscillations. It depends on the time of day, there are values of up 1500 us/cm to minimum values of 500 us/cm. There are also strong oscillations in TOC and turbidity. TOC recorded maximum values of 1.8 mg/L and turbidity records a maximum of 2.1 FTU.

To see more closely the relationship between these three parameters, Graph 80 is presented.

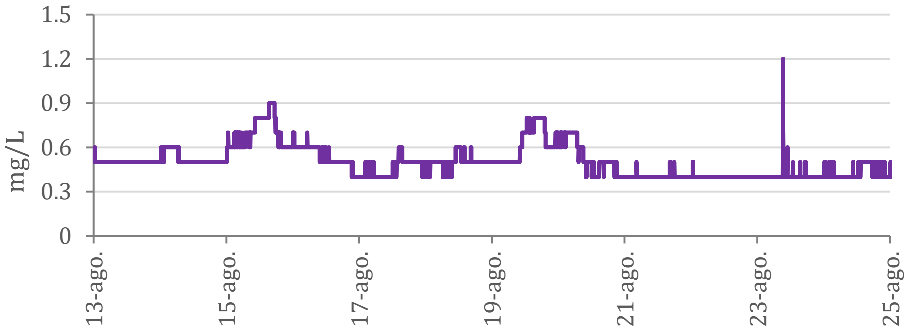


Graph A.80: *TOC, Turbidity and Conductivity registered by pipe::scan from February 10 to February 17, 2019.*

Regarding conductivity there are many variations throughout the month that are due to a change of water due to the demand of the area. These variations cause TOC peaks throughout the month of February.

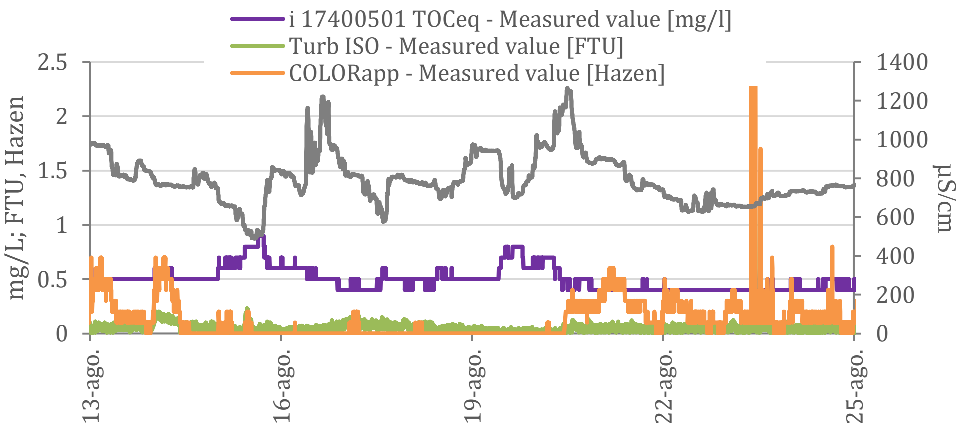
10.2.4 Internal problems

August 2018



Graph A.81: *TOC parameter registered by pipe::scan from August 13 to August 25, 2018.*

During the month of August, there are two small peaks, since the difference is four tenths and there is no out of control parameter. A higher peak appears, on the 23rd at 12 noon where a maximum value of 1.2 mg/L is recorded. TOC parameter is compared with the parameters of turbidity, colour and conductivity in graph A.82:

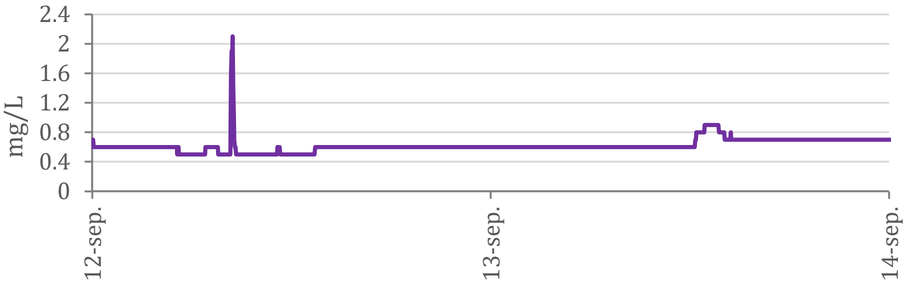


Graph A.82: *TOC, Turbidity, Colour and Conductivity registered by pipe::scan from February 10 to February 17, 2019*

In Graph A.83 it can be observed how just in the strong peak of the TOC there is also a peak of turbidity and a peak of colour. Just at this point, conductivity shows no variation.

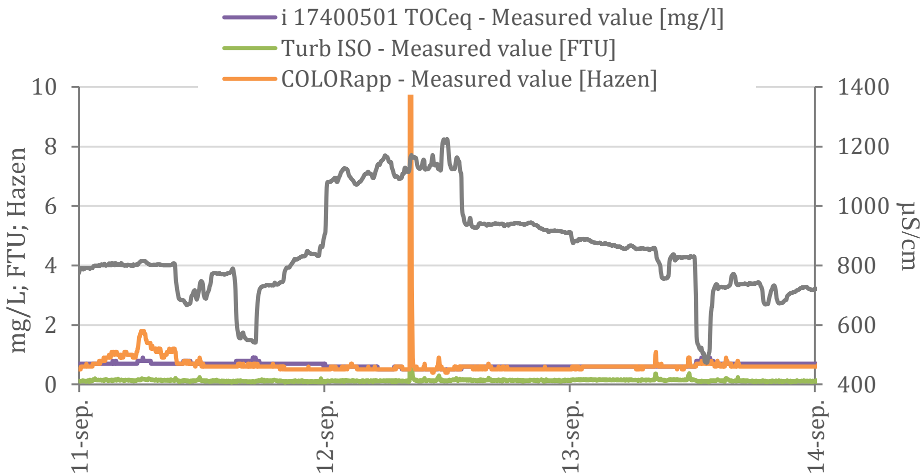
Therefore, in this event the rise of TOC cannot relate with a change of water since the conductivity in this period of time is constant.

September 2018



Graph A.83: *TOC parameter registered by pipe::scan from September 12 to September 14, 2018*

On December 12 at 8:30 in the morning the TOC has a peak that marks a maximum concentration of 2.1 mg/L (the previous value is 0.5 mg/L). The time interval where this increase of the concentration occurs is 10 minutes (from 8:22 to 8:32). The concentration of TOC is then stable with small oscillations. TOC parameter is crossed with conductivity, turbidity and colour:



Graph A.84: *TOC, Turbidity, Colour and Conductivity registered by pipe::scan from February 10 to February 17, 2019*

It can be observed on graph A.84 that on day 12 at 8:22 in the morning the colour and turbidity have a very significant rise. The colour measures a maximum value of 13.2 Hazen while the turbidity measures a value of 4,855 FTU. Although the highest value is recorded a few minutes later and reaches 8.22 FTU (6 minutes later). The conductivity does not present any variation just in this time interval.

In this case, the increase in concentration of TOC is not due to a change of water since the conductivity does not suffer any variation in this time interval.